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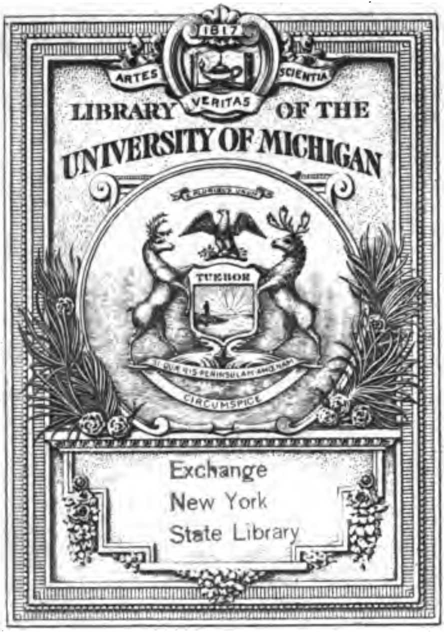

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1919

VOL. XX—NO. 59, PART 3

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1919

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STATE OF NEW YORK

Thirty-first Annual Report
of the
New York State College of Agriculture at Cornell University
and of the
Agricultural Experiment Station

Established under the Direction
of Cornell University
Ithaca, New York

1918

VOLUME I

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THIRTY-FIRST ANNUAL REPORT

OF THE

New York State College of Agriculture at Cornell University and of the Agricultural Experiment Station Established under the Direction of Cornell University

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STATE OF NEW YORK

DEPARTMENT OF AGRICULTURE

ALBANY, January 15, 1919

To the Honorable the Legislature of the State of New York:

In accordance with the provisions of the Statutes relating thereto, I have the honor to transmit herewith the Thirty-first Annual Report of the New York State College of Agriculture at Cornell University, as a part of the Twenty-sixth Annual Report of the Commissioner of Agriculture.

CHARLES S. WILSON,
Commissioner of Agriculture.

NEW YORK STATE COLLEGE OF AGRICULTURE

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James Chester Bradley, Ph.D., Assistant Professor of Systematic Entomology, Exchange Professor at University of California, 1917–18.
John Bentley, jr., B.S., M.F., Assistant Professor of Forest Engineering.
George Charles Embody, Ph.D., Assistant Professor of Aquiculture.
Mrs. Helen Binkerd Young, B.Arch., Assistant Professor of Home Economics.
Mrs. Anna Botsford Comstock, B.S., Assistant Professor of Nature Study.
Harry Morton Fitzpatrick, Ph.D., Assistant Professor of Plant Pathology.
Byron Burnett Robb, B.S. in Agr., M.S. in Agr., Assistant Professor of Rural Engineering.
Walter Warner Fisk, M.S. in Agr., Assistant Professor of Dairy Industry.
Vern Bonham Stewart, Ph.D., Assistant Professor of Plant Pathology.
Annette J. Warner, Assistant Professor of Home Economics.
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Lex Ray Hesler, Ph.D., Assistant Professor of Plant Pathology.
William Howard Rankin, Ph.D., Assistant Professor of Plant Pathology.
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Forest Milo Blodgett, Ph.D., Assistant Extension Professor of Plant Pathology.
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Montgomery Robinson, Litt.B., B.S., Assistant Professor in Extension Service.
Wesley Worth Warsaw, B.S. in A.E., Assistant Extension Professor of Soil Technology.
Paul Work, A.B., M.S. in Agr., Acting Professor of Vegetable Gardening.
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Bertha E. Titsworth, B.S., Assistant Extension Professor of Home Economics.
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Beulah Blackmore, Assistant Professor of Home Economics.
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Louis Arthur Zimm, B.S., Instructor in Plant Pathology.
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Ada Eljiva Georgia, Assistant in Natural History.
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R. J. Morgan, Assistant in Soil Technology.
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ALVIN C. BEAL, Ph.D., Floriculture.
MORTIER F. BARRUS, Ph.D., Plant Pathology.
CLYDE H. MYERS, M.S., Ph.D., Plant Breeding.
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JAMES C. BRADLEY, Ph.D., Entomology.
PAUL WORK, B.S., A.B., Vegetable Gardening.
JOHN BENTLEY, Jr., B.S., M.F., Forestry.
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EARL W. BENJAMIN, Ph.D., Poultry Husbandry.
JAMES K. WILSON, Ph.D., Soil Technology.
EMMONS W. LELAND, B.S.A., Soil Technology.
CHARLES T. GREGORY, Ph.D., Plant Pathology.
WALTER W. FISK, M.S. in Agr., Dairy Industry.
ROBERT MATHESON, Ph.D., Entomology.
HARRY H. KNIGHT, Pg.B., B.S., Entomology.
MORTIMER D. LEONARD, B.S., Entomology.
FRANK E. RICE, Ph.D., Agricultural Chemistry.
IVAN C. JAGGER, M.S. in Agr., Plant Pathology (In cooperation with Rochester University).
WILLIAM I. MYERS, B.S., Farm Management.
LEW E. HARVEY, B.S., Farm Management.
LEONARD A. MAYNARD, A.B., Ph.D., Animal Husbandry.
LOUIS M. MASSEY, A.B., Ph.D., Plant Pathology.
BRISTOW ADAMS, B.A., Editor.
LELA G. GROSS, Assistant Editor.

PRESIDENT'S LETTER OF TRANSMITTAL

June 30, 1918

The Governor of the State of New York,
Albany, New York.

The Secretary of the Treasury,
Washington, D. C.

The Secretary of Agriculture,
Washington, D. C.

The Commissioner of Agriculture,
Albany, New York.

The Act of Congress, approved March 2, 1887, establishing Agricultural College Experiment Stations in connection with the Land Grant Colleges, contains the following provision: " It shall be the duty of each of said stations, annually, on or before the first day of February, to make to the Governor of the State or Territory in which it is located, a full and detailed report of its operations, including a statement of receipts and expenditures, a copy of which report shall be sent to each of said stations, to the said Commissioner of Agriculture, and to the Secretary of the Treasury of the United States."

And the Act of the Legislature of the State of New York, approved April 12, 1906, providing for the administration of the New York State College of Agriculture at Cornell University, contains the following provision: " The said University shall expend such moneys and use such property of the State in administering said College of Agriculture as above provided, and shall report to the Commissioner of Agriculture in each year on or before the first day of December, a detailed statement of such expenditures and of the general operations of the said College of Agriculture for the year ending the thirtieth day of September then next preceding." This was amended by the act of April 3, 1916, which changed the fiscal year to end June 30.

In conformity with these mandates I have the honor to submit on behalf of Cornell University the report of the New York State College of Agriculture for the year 1917–18.

I commend this report to the careful consideration of the Governor and the Legislature. The State makes liberal (if not always quite adequate) appropriations for the maintenance of its College of Agriculture, and it is the duty of the authorities of the State to satisfy themselves that the appropriations have been wisely and economically administered. This is a standing reason for careful scrutiny of the annual report of the State College of Agriculture. I merely desire to repeat what I said last year, namely, that there is now an additional, special, and momentous reason due to the existence of war and the imperative demand for an increased production of foodstuffs, on which, indeed, the issues of the war may finally depend. And there is no other agency in the State of New York which can do so much, or which, in my opinion, is doing so much, to stimulate and enlarge agricultural production as the State College of Agriculture, including the young men and women who have studied in the institution in the past, the present student body, and, above all, the members of the faculty of the College, whose ability, zeal, and devotion to the cause, whether before students in classrooms and laboratories, or in conferences and meetings of farmers throughout the State, are beyond all praise.

Respectfully submitted,

JACOB GOULD SCHURMAN,
President of Cornell University.

REPORT OF THE DEAN OF THE NEW YORK STATE COLLEGE OF AGRICULTURE

June 30, 1918

To the President of the University:

Sir: I have the honor to submit herewith a report of the work of the New York State College of Agriculture for the year 1917–18.

The enrollment

The registration of students in the College of Agriculture for the year 1917–18, shown in comparison with the preceding year, is as follows:

		1917–18	1916–17
Regular undergraduate students:			
Freshmen	319		
Sophomores	264		
Juniors	246		
Seniors	203		
		1,032	1,747
Special students		44	86
Winter-course students:			
Agriculture (General)	108		
Dairy Industry	23		
Home Economics	23		
Poultry Husbandry	15		
Fruit Growing	8		
Flower Growing	7		
Vegetable Gardening	6		
		190	282
Summer-school students		405	382
Total		1,671	2,497

The decline in the winter-course enrollment, which has been constant now for some years, is due only partially to the war. There seems to be a lessening need for such courses with the widespread introduction of agriculture into the high schools of the State. The time has not yet come, however, when they can be discontinued.

It is to be noted that there was an increase in the number attending the Summer School in Agriculture. This seems to be due primarily to the fact that the College offered courses in physical training in order to prepare supervisors of physical training for the rural schools in accordance with the recently enacted physical training law. Approximately 125 persons registered for these courses.

Legislative appropriations

The generous appropriations made by the Legislature in 1917, while inadequate to meet many greatly needed developments in the College, were nevertheless sufficient to maintain the College during this year of excessive costs, and we shall be able to close the year within our available funds. (See the financial report in this volume.) The 1918 Legislature, whose sessions were recently brought to an end, has also made substantial provision for the maintenance of the College. We recognize that the large funds appropriated impose a very responsible trust on the administration of the College and of the University to see that all expenditures are wisely and efficiently made. The burden of responsibility grows each year with the expansion of the work, both resident and in extension, to meet new needs as they arise.

In this connection attention is called to the transfer of the farmers' institute work, hitherto conducted by the State Department of Agriculture, to the State College of Agriculture as part of its extension service. It has long been recognized that this transfer should be made, as the institutes are a form of educational extension — a function which has been vested in the College. The State Department of Agriculture, or the Department of Farms and Markets as it has now been named, is more strictly a regulatory department, charged with the administration of the agricultural law.

Among the more important additions made by the 1918 Legislature are provisions for the following: a new full professor in vegetable gardening; a full professor and an assistant professor in rural engineering; three assistant professors in home economics; two professors in rural education to meet the obligations of the Smith-Hughes work; two assistant state leaders in the home demonstration work. An appropriation of $7500 was made for the erection of an insectary, or laboratory, for economic investigations of insects, and one of $2000 for the underdrainage of the plant-breeding and floricultural experimental grounds.

Two financial problems of first importance to the welfare of the College still confront us, however. One of these is the urgent necessity for additional buildings to house some of the departments; the other is the insistent need for salary increases for members of the staff.

The college buildings have been very greatly overcrowded for a number of years and the congestion grows constantly worse. The Departments of Plant Pathology, Botany, Pomology, Floriculture, Entomology, Rural Engineering, and Rural Economy are crowded into only a fraction of the space needed for their present work, and the conditions are dispiriting to the men. Certain other departments are but little better off. The excessive costs of building during the war period and the need of skilled labor for war work have dictated that we should not seek appropriations from the State for these purposes at the present time. It is part of our public obligation to get along as best we can with present facilities until the war ends. Thereafter we shall need as soon as possible to seek funds for the erection of additional buildings.

The situation in respect to salaries is even more acute. Because of the serious financial situation confronting the State it seemed best to the trustees this year not to request increases in salaries for members of the teaching staff. We find, however, that under the impetus of the nation-wide movement for increased food production, very large appropriations have been made for agricultural purposes in most if not all of the States; and the United States Department of Agriculture has received vast war funds from Congress. On every hand new lines of war work are being developed and old lines extended. The inevitable result is an overwhelming demand for trained men. Many very valuable young teachers have already gone from us, and a number of our full professors have received financially alluring invitations to go elsewhere. It would be opposed to the interests of the State to allow our staff to be depleted of its most able teachers.

Since its creation as a state institution, the College of Agriculture, by reason of its being charged with the field of extension teaching, has been looked upon as the chief agency in the State to give immediate assistance to farmers in their practical problems of crop production. This obligation has grown with the years, and it has been multiplied under the stress of war. Unless we can retain against the bidding of other States and the United States Department of Agriculture the men needed for the war-time extension activities of the College, we shall fail of what the State has a right to expect of us just at the period when the severest test is being made of our ability to serve farmers.

Activities of the College in relation to the war

At the time of the entrance of the United States into the war, the University adopted the policy of giving to students who were leaving to enter the land or the naval forces of the country, or to engage in industrial or other enterprises contributing to the success of such forces, full credit for such courses as they were then carrying. The university faculty ruled that agricultural work was within the scope of this resolution. Under this legislation a total of 794 students left the College in April and May, 1917. Of these 567 went into agriculture, 184 into army, navy, or ambulance corps, and 43 into munition factories and other industries. While there was practically no evidence of abuse of the privileges offered by this legislation, it was generally agreed that no such liberal arrangement need again be made. In March, 1918, it was determined that credit should be given only to seniors directly entering the army or navy not more than six weeks before their graduation. Only six students have needed to make use of the privilege. In a few cases the faculty of the College has relieved seniors from further residence if all scholastic requirements had previously been wholly met.

It was regarded as both unnecessary and inadvisable to release students from any part of their regular work after the spring of 1917, but at the same time it was thought that some advantage could be gained by consolidating the work of the year. Accordingly, in the first term of 1917–18, it was decided to shorten the Christmas holidays by two days and to omit all other vacations, bringing Commencement forward to May 22. This program has worked satisfactorily.

The efforts of trustees and faculty to put the University on a war basis have met with whole-hearted support from the student body. No objection has been made to the abolishment of vacation periods or to the decrease of athletic and social privileges. The several courses preparatory for war service given in the engineering schools have been well attended.

The record of the number of present and former students entering the army and navy is necessarily very incomplete, as doubtless there were many of both groups who enlisted or were drafted and sent no notice of the fact. At the close of the college year 1917–18, we have record of 506 present and former students in the land forces, while 130 have enlisted in the navy. Of the latter, 13 were in the naval reserve and were allowed to complete the year.

In addition to the various organized emergency plans of the College, many members of the staff have engaged in personal work as opportunity and time presented. Some of this work has been done at Ithaca in addition to college duties, although the greater part has been performed during vacations and official leaves of absence granted for the purpose.

When Governor Whitman appointed the New York State Food Supply Commission for patriotic agricultural service on April 13, 1917, he named the Dean of the College and Professor Maurice C. Burritt, the Vice-Director of Extension, as members. The Dean was made secretary of the Commission and Commissioner in Charge of Food Conservation including insect and plant-disease control work. Professor Burritt had charge of the Division of County Organization and relations with the Farm Bureaus.

When the Commission was discontinued and its work was taken over by the newly created New York State Food Commission, the membership of the Dean and Professor Burritt ceased, although the University is still represented by President Schurman, one of the three commissioners who is charged with the field of food conservation, and Professor H. E. Babcock, formerly State Leader of County Agents, whom the College released to assist President Schurman. Professor Babcock was made director of the Division of Food Conservation.

Professor Bristow Adams devoted his vacation in 1917 to the Office of Information, United States Department of Agriculture, where he worked out a number of publicity campaigns for agricultural production including that on seed corn. A number of other campaigns were devoted especially to aiding the efforts of the Bureau of Markets and the States Relations Service. At the same time Professor Adams was giving volunteer service to the Federal Food Administration in connection with its publicity work. He has contributed poster designs to the National Garden Commission and to the Boys' Labor League of the Federal Department of Labor, and has furnished material which has been used in the Liberty Loan campaigns.

Dr. Elmer E. Barker has been making abstracts of the literature of little-known plant products for the Raw Products Committee of the National Research Council.

Professor George W. Cavanaugh is cooperating with the Federal Government in maintaining the purity of the milk supply for army camp hospitals, and is also making chemical tests for the detection of possible poisonous materials in supplies for the Red Cross.

During the summer vacation of 1917, Professor Lewis J. Cross was employed by the Federal Bureau of Chemistry as an investigator in the drying of vegetables. He canvassed the growing sections of western New York, and was located at Albion for some time. Professor Cross expects to be engaged in the same work this summer.

The Dairy Division of the United States Department of Agriculture has been waging a campaign for the better use of cottage cheese as a means of utilizing surplus skimmilk. Professor Walter W. Fisk spent the summer vacation of 1917 in the capacity of general organizer for this work, his time being divided between a number of eastern States. Professors Harold E. Ross and Hugh C. Troy spent the summer in the same campaign. Seven other members of the Dairy Department inspected the making and packing of the butter supply for the Department of the Navy last summer. This work was largely done in New York, Michigan, and Pennsylvania.

Professor Ralph S. Hosmer has been giving considerable time to the work of the New York State Wood Fuel Advisory Board, to which he was appointed on December 26, 1917. This board works in cooperation with the New York State Conservation Commissioner and the State Fuel Administrator. On December 26, 1917, Professor G. Harris Collingwood was likewise appointed as district agent under the Wood Fuel Advisory Board, to promote the use of wood fuel. This duty occupied a considerable portion of his time during the months of January, February, and March. During March Professor B. A. Chandler was engaged in similar duty, in cooperation with Professor Collingwood.

Professor Arthur B. Recknagel was granted leave of absence from the University from July 1, 1917, to June 30, 1918, to permit him to serve as Secretary to the Empire State Forest Products Association. He is also a member of the war committee of the Society of American Foresters, whose duty it is to assist the Government, particularly as regards the utilization of forests for war purposes.

Professor Paul J. Kruse left the College on May 1 to do vocational testing for the Government. Examinations will be arranged to determine the degree of proficiency of men who claim exemption on account of being skilled workmen.

Professor Ralph W. Rees spent his vacation with Mr. E. H. Anderson, agriculturist for the New York Central Railroad with headquarters at Buffalo. His work is in the perishable freight department, where there has been an abnormal loss of food products during the last few months which the company thinks is partly due to the tendency to overload cars in attempting to carry out the full-car program.

Professor William A. Riley was a member of the sub-committee on Medical Zoology of the Division of Medicine of the National Research Council.

Professor Martha Van Rensselaer was given a six-months leave of absence on March 1, to take the position of Director of the Home Conservation Division of the United States Food Administration. This appointment insures close cooperation between the College and the Federal Commission. Miss Claribel Nye was given leave of absence to act as assistant to Miss Van Rensselaer.

As Chairman of the War Emergency Board of American Plant Pathologists, Professor H. H. Whetzel has devoted considerable time and energy since the first of the year to assisting in the organization and development of cooperative coordination of plant-disease control work of an emergency character among pathologists throughout the United States.

New York State is making a determined effort to increase production by stimulating home gardening by boys and girls. Professor F. L. Griffin is state leader of this movement. Professor Edward A. White is supervisor for western New York and has visited thirty-seven cities and towns, conferring with superintendents of schools, chambers of commerce, and other organizations. Miss Alice L. Peck, Miss Nancy McNeal, and Mrs. Alice V. Crandall are giving full time to this organization and to supervision of this undertaking among the boys and girls of the State by means of junior home projects.

Last summer the Farm Cadet Bureau of the Military Training Commission established several boys' camps in agricultural districts throughout the State. City boys from sixteen to twenty years of age were hired out to the farmers in the locality, and formed a very valuable asset to the labor supply of the region. Professor George A. Works spent considerable time between June 1 and September 30 in inaugurating and supervising these camp communities.

The chief emergency work of Professor George F. Warren and the staff of the Department of Farm Management has been the tabulation of the state agricultural census. Much of Professor Warren's time has been spent in giving information to various food authorities and investigators.

The war work of the Department of Home Economics is described in the report of that department.

Teachers in the military forces of the country

The following members of the teaching staff of the College have left to join the military forces of the country either by enlistment or under the draft:

Lewis Knudson, Professor of Botany. Y. M. C. A. service in France.

Paul Work, Acting Professor and Superintendent of the Department of Vegetable Gardening. Second Lieutenant, 304th Engineers, Camp Meade, Maryland.

Leonard Amby Maynard, Assistant Professor of Animal Husbandry. First Lieutenant, Gas Defense Service of the Sanitary Corps, in France.

Edward Riley King, Assistant Professor of Entomology. Aviation Service.

Edwin Sleight Ham, Instructor in Animal Husbandry. Ammunition Train, Quartermaster's Corps.

Harry E. Knowlton, Instructor in Botany. Artillery Officers' Training Camp, Camp Upton, South Carolina.

Harry Hazelton Knight, Instructor in Entomology. Instructor in Aviation Photography, Ithaca, New York.

Louis Arthur Zimm, Instructor in Plant Pathology. Coast Artillery, Fort Strong, Massachusetts.

Edwin Fraser Hopkins, Instructor in Plant Pathology. Research Work, Ordnance Department, Washington, D. C.

Lawrence Joseph Norton, Instructor in Farm Management. Camp Meade, Maryland.

George Robinson Phipps, Instructor in Extension Service. Captain, Personnel Division, Office of Chief Signal Officer, Washington, D. C.

Howard Jerome Ludington, Instructor in Extension Service. Ambulance Service.

Cedric Hay Guise, Extension Instructor in Forestry. Instructor in Ground School of Aviation, Ithaca, New York.

Harold Deane Phillips, Instructor in Rural Economy. First Students' Battery, Officers' Training Camp, Camp Dix, Wrightstown, New Jersey.

E. W. Lindstrom, Investigator of Bean Production. Aviation Service, Ellington Field, Houston, Texas.

Progress in research

The members of the research staff of the College and Experiment Station have continued their investigations with undiminished zeal. Many of these researches are of long duration, and the more important of these have been mentioned in earlier reports. An adequate report of the progress in research during the year would necessitate reviewing many of the long-established research projects, and limits of space forbid this. Suffice it to say that the conditions created by the war only confirm our conviction as to the high importance to the State and the Nation of the kind of investigations now under way; and that in the interest of the Nation they must be safeguarded to the fullest possible extent from the encroachments of war. The food situation created by the war has revealed more clearly than ever to our state and national leaders the fundamental dependence of the people on the results of agricultural research. The future should see larger public support given to such work.

Further statements regarding the progress of research are made in the departmental reports included later in this volume; and the bulletins reporting the results of investigations are bound as part of this report.

The investigation of bean production

Pursuant to legislative enactment, chapter 306, Laws of 1917, the New York State College of Agriculture at Cornell University has undertaken the commission of making an investigation " of the bean production in the State, including the ravages of diseases and of insect pests, the breeding of disease-resistant or improved varieties, and of such other matters in relation thereto as such college of agriculture may determine." For the purposes of this investigation, experts in entomology, plant breeding, and plant pathology have been employed and all necessary facilities and accumulated information at the College placed at their disposal. During the summer months the investigation has been conducted at a temporary field laboratory located in a bean field at Perry, New York. Records and observations have been made in all the important bean-producing sections of western New York. Considering the very unfavorable season for bean production, the experts have made notable progress in their work. There has been the closest possible cooperation in all the work, and the whole project has been pushed forward with the idea of finding methods of improving the conditions for producing beans.

During the past few years snails have been one of the most serious pests of beans and have evidently caused considerable loss. These were therefore among the first pests to which attention was given. The first step in this work was to learn something of the habits and mode of life of snails, since nothing was known regarding them. Mr. I. M. Hawley has succeeded in finding the eggs and in determining where they are deposited, how long it takes them to hatch, and the number of generations produced in a season. He has obtained many other valuable data concerning the life history, habits, and distribution of snails throughout the bean districts. He has also been able to determine something regarding the losses caused by these mollusks. Many different substances were tested in attempts to control the snails and prevent their ravages. Spraying experiments with arsenate of lead alone, with arsenate of lead sweetened with molasses and sugar, with Black-leaf-40 tobacco extract, and with sweetened sodium arsenate, and dusting experiments with tobacco, tobacco and lime, and powdered arsenate of lead, were made with a view of repelling or killing the snails. Fortunately this work can be carried on in the greenhouse during the winter, and some promising mixtures for the control of snails are now being tested.

Many valuable data have been accumulated on the distribution, injuries, habits, and life history of the seed-corn maggot, which proved the most serious pest on beans in New York State during the season of 1917. At Brockport a grower planted half of his 12-acre field three times when beans were worth $10 a bushel, and then failed to get a stand. Other similar instances occurred here and there throughout the bean-growing districts. Extensive experiments in control were tested during the season. Seed beans were treated with over a dozen different materials with the idea of repelling the maggots and preventing their attacks on the beans in the soil. The most promising method of control is shallow planting of the seed. This fact was learned accidentally, but is none the less valuable and needs careful investigation and trial for two or three seasons.

Other pests that have been investigated to some extent are millipedes, leaf-hoppers, and June bugs.

The bean-disease expert employed in the investigation had had a previous experience of two years in studying bean diseases. He had already established the fact that dry root rot is caused by a parasitic fungus and that it is one of the very important diseases of the bean, and had determined from extensive experimentation that none of the common methods of soil disinfection or sanitation are of value in its control. It seemed that the method of control of this and of some other bean diseases lay in the possibility of finding plants resistant to disease, and in the improvement of such strains either by selection or by hybridization. The disease expert and the breeder, therefore, have joined forces in work of this nature.

A few bean plants of a non-commercial variety have been discovered which are resistant to the dry root rot. These have been crossed with the commercial white marrow bean, and the second generation was grown in disease-infested soil this season.

One hundred and thirty varieties of beans and nearly five hundred plant selections, made the preceding year, were tested in disease-infested soil to determine their relative value and their susceptibility to the dry root rot disease. Records were made on all, and some were found which apparently resisted the disease.

Numerous crosses of different bean varieties were made with the idea of isolating a good commercial type resistant to root rot. Seed from these crosses is being grown in the greenhouse so that the results can be tested in the field in 1918.

About one thousand plants of a cross between the anthracnose-resistant red kidney bean and the white marrow bean were grown this season, in order to secure a white marrow which would not be susceptible to anthracnose.

Connected with the above lines of experimentation is a great amount of technical detail that need not be mentioned here. In addition to the above work, the disease expert has studied two other root diseases of the bean, black root rot and Rhizoctonia root rot, and has found that they are of less economic importance than the dry root rot. He has also obtained records for a study of the relation of weather conditions to the prevalence of root rot, and is now engaged in a study of the relation of soil moisture and soil temperature to infection of the bean plant by the fungus causing dry root rot.

The plant breeder has taken records on over five hundred rows (ten feet each) of beans selected for increased yield. Extensive selections in various bean sections have been made. A great number of exceptional plants have been found which give promise for improvement in yield and in uniformity. Additional selections were made also for disease-resistant plants.

Bean mosaic is a disease which has been prevalent in the State for only two years. It is already very generally distributed, especially on pea beans, and infection in many fields is as high as 100 per cent. Some bean fields have been abandoned in midsummer because of the disease. Badly affected plants bear few pods or none at all. The disease is infectious but its cause has not been determined. It cannot be prevented by hill selection, for seeds from plants selected for their healthy and vigorous appearance have developed 100 per cent of diseased plants. A strain of pea bean has been found which apparently is resistant to the disease. Tests of this should be made just as soon as possible.

The work thus far done only serves to emphasize the great necessity for further investigation. Bean growers are discouraged with the low yields they have been getting, and many of them have stated that they cannot continue in the business unless relief comes soon. It has been found that the important problems are not of easy or quick solution. The apparent methods of attack of these problems require long and persistent effort, and this is being consistently applied. In the case of remedial treatments, the results of a single season cannot be used as a basis for reliable recommendations; and in the case of breeding, several generations of plants must be secured before it can be determined that types have been fixed. The work certainly should be continued on the same basis as for the current year.

Staff appointments and changes

On October 1, 1917, Bernard A. Chandler was appointed Acting Assistant Professor of Forest Utilization for the period of the college year. During the year Professor Chandler has been engaged in forest investigation work, mainly in the Adirondacks.

From July 1, 1917, to June 30, 1918, Professor A. B. Recknagel, of the Department of Forestry, was on leave of absence, granted by the University to permit him to act as Secretary to the Empire State Forest Products Association. During this period Professor Recknagel has done much to advance the cause of forestry among the lumbermen of the State.

Extension activities in the Department of Animal Husbandry have been materially strengthened by the appointment of Mark J. Smith, a sheep specialist, as an Assistant Extension Professor.

For the first time definite provision has been made in the Department of Rural Economy for the much-needed development of its extension work, by the appointment as Extension Professor of Rural Economy of James E. Boyle, at present of the staff of the Bureau of Markets of the United States Department of Agriculture, and earlier of the North Dakota Agricultural College and the University of North Dakota. He will take up his work at the beginning of the next college year.

During the year Professor E. C. Van Dyke, of the University of California, held appointment in the Department of Entomology as an Exchange Professor. Professor J. C. Bradley, of our own Department of Entomology, was granted leave of absence to accept appointment to take Professor Van Dyke's work in the University of California.

The work in vegetable gardening, both teaching and extension, suffered a severe blow with the drafting for military service of Acting Professor Work, Superintendent of the Department. It seemed best, in order to take care of the work in vegetable gardening, to unite for the period of the war the Departments of Vegetable Gardening and Farm Crops under E. G. Montgomery, Professor of Farm Crops. This consolidation was accomplished last fall, and it gives every promise of being a happy arrangement.

The enlargement of our facilities for the training of teachers, involving several appointments to the staff, is separately treated in the following paragraphs.

The training of teachers of vocational agriculture and home economics

On February 23, 1917, President Wilson signed the Smith-Hughes Act. Among the features of this law is a provision for granting to the States, under certain stipulations, federal funds to be used in the preparation of vocational teachers of agriculture, home economics, and trades and industries. The allotment to New York State for the year beginning July 1, 1917, was $49,714. Provision is made by which in four years time this amount will be doubled. The State must provide an equal amount, so that for the year 1920–21 there will be available from state and national sources a minimum of approximately $200,000 for these purposes in New York State. Within the State this act is administered by the State Department of Education, and this authority has designated the New York State College of Agriculture at Cornell University for the training of teachers of agriculture and as one of the two institutions to prepare teachers of home economics under the provisions of this legislation.

Partly under the impetus provided by this act, four new members have been added to the staff of our Department of Rural Education. Professor William F. Lusk, Ph.B., M.S., came to the Department after several years of experience in the University of Minnesota. Assistant Professor Paul J. Kruse completed the requirements for his doctorate at Columbia University just before coming to the Department, but he had been for some time previously a member of the staff of the College of Education in the State University of Washington. Professor Rolland M.

Stewart, previous to coming to Cornell, was an assistant professor in the University of Iowa for six years; he had completed the requirements for the doctor's degree at Iowa. Professor William S. Taylor came from the University of Texas, where for five years he was Associate Professor of Agricultural Education. He had been in our Department for only a few weeks when Pennsylvania State College offered him a position as head of the Department of Rural Education. This position Professor Taylor accepted, and he left on April 1 to take up his duties in Pennsylvania.

It has been necessary to provide a course in farm shop work in the Department of Rural Engineering, for the conduct of which Mr. L. M. Roehl was appointed; and similarly a shop course in Home Economics, with Miss M. G. Ingersoll in charge.

In cooperation with the local school authorities a demonstration department of vocational agriculture has been established at Trumansburg. Plans are under way to extend this feature to cover home economics next year.

Summer school

Previous to the opening of the summer school in 1917 the requirements for admission were raised. Provision was made by which those persons engaged in educational work were admitted regardless of previous academic preparation; others were required to have completed at least two years of work in Cornell University or some other institution of equal standing. These changes were made in order that this session of the College might serve in a larger measure the needs of teachers, supervisors, and superintendents. In spite of the increased requirements and the effect of the war, the attendance increased from 382 in 1916 to 405 in 1917.

The State Game Farm

By act of the New York State Legislature, chapter 747, Laws of 1917, there was established a New York State Game Farm as part of the State College of Agriculture, to be administered by the trustees of Cornell University. Under authority of this act a tract of 176 acres, adjacent to the college farm on the east, has been purchased.

Recognizing that we are at the beginning of knowledge of our plant and animal resources, this new educational enterprise takes for its scope the wild life of New York State and the conservation of all that is valuable on it. Beginning with the rearing of game birds and waterfowl, to replace in some measure these rapidly vanishing wild groups, it is expected that this work will be extended to the conservation and care of fur-bearing animals, of valuable song birds, of wild flowers and useful native shrubbery, and of every wild thing that gives promise of being used for the material or educational betterment of the people. All life was once wild life. Agriculture has grown by selection and care of the best that nature offers. This work is initiated in the firm belief that the sources of our benefits in nature are by no means exhausted.

The object of the game farm is to afford opportunity for instruction in game breeding and the conservation of wild life. Breeding of ring-necked pheasants and mallard ducks will be conducted during the first season of its operation, and in succeeding years the work will be enlarged to include other species of useful game birds, fishes, and other animals. Emphasis will be given to the correlation of game breeding and different types of farming in New York State. Progress is being made already in stocking and equipping the farm for teaching and research.

Instruction in wild life conservation and in game breeding is offered in the following courses: (1) the regular four-years course in agriculture, in which students may include among their elections the subjects that are fundamental to wild life conservation and game breeding; (2) a short course of twelve weeks (to be followed by one or more seasons of work on a game farm) to give practical training in the technique of game breeding; (3) a series of public lectures given by experts in the various lines of wild life conservation. During the second term of the current year a series of thirty-one lectures on various phases of wild life has been given by nineteen lecturers, men eminent as authorities in the field. This series was made possible by the generous cooperation and assistance of the lecturers who gave their services, and of Mr. Frederick C. Wolcott, who provided money for the payment of traveling expenses.

The Extension Service

The administration of extension work was in a measure reorganized on July 1, 1917. The former Department of Extension Teaching, the Office of Publications, the Central Office of County Farm Bureaus, and the newly created Central Office of County Home Demonstration Agents, were combined to form the Extension Service under the immediate headship of Professor M. C. Burritt, who was made Vice-Director of Extension, the Dean of the College being the Director of Extension. This organization is administrative and functions as a branch of the Dean's Office.

It was thought expedient to reduce the number of five-day extension schools in the past winter. Twenty-nine were held in twenty counties, with a total enrolled membership of 993, an average of 34.2. These figures do not include visitors and high school students who attended irregularly. There were also held at the College, under the supervision of the Department of Rural Engineering, two special tractor schools, each of three weeks duration, for the training of operators. The first of these had an enrollment of 40, the second 37. In addition twenty tractor schools were held in nineteen counties in cooperation with the State Food Commission. These had a total enrollment of 1176, or an average of 58.8 per school.

A partial summary of single-day meetings arranged by the Extension Service during the first half of the year show an aggregate attendance of more than 14,000 persons at about 450 meetings.

Exhibits were sent to the State Fair, to the Rochester Industrial Exposition, to six county fairs, to the meeting of the New York State Fruit Growers' Association, and to the meeting of the Western New York Horticultural Society.

The eleventh annual Farmers' Week had a registered attendance of 3095 for the week. Special prominence was given on the program to subjects relating to food production and conservation.

A demonstration car for instruction in the grading and storage of potatoes was run over the lines of the Lehigh Valley Railroad in seven counties, making 28 stops with an attendance of about 400.

The available reading-course lessons have been classified, and bound sets have been prepared for the use of county farm bureau offices, granges, and other institutions and individuals. An effort has been made to increase the use of the reading course through closer cooperation with the county agents. Since July 1, 1917, 10,000 new names have been added to the mailing list. At the close of the year the total number of readers exceeds 31,000.

Shortly after the United States entered the war and renewed emphasis began to be placed on increased food production, there came a great demand from school authorities for assistance in the development of school and home gardening. Fortunately, Congress made funds available through an emergency appropriation, which has made possible a marked development of the junior extension activities under Professor F. L. Griffin, State Leader of Junior Extension Work.

Office of Publication

The issuing of publications has been better systematized in the past year. The war has made new and unprecedented demands for emergency publications bearing on the problems of food production and food conservation. A great number of these, mainly of the " how-to-do-it " type, have been published on short notice.

The information service connected with the Office of Publication has kept the people of the State informed, through the cooperation of the press, of helpful and timely facts connected with the problems of food production and food saving. This service is growing more effective year by year, because it is absolutely removed from any idea of publicity but aims to popularize the results obtained where they are of benefit to the army of farm and home readers.

During the past year this information service has conducted campaigns on wheat-saving menus, for greater milk consumption, for larger use of potatoes, and for home gardening and food preservation. A record of actual printings of its items as seen by the College shows that these reach the amazing total of 43,000,000 printings. Items seen by the College undoubtedly represent only a comparatively small proportion of the total.

Office of the State Leader of County Agents

War emergency conditions brought upon the farm bureau organization new obligations and a vast amount of detail, much of it government work, requiring immediate and careful attention. The bureau provided the machinery through which the various federal, state, and other public agencies chiefly made contact with farmers. They provided at once county clearing houses for governmental projects such as the census, seed exchange, supply of labor, and organs for responsible expression of their needs by farmers.

Fifty-five counties have active farm bureau organizations. The new bureaus have come in with large memberships, and the percentage of total farmers belonging to the farm bureau associations has steadily increased from 11 in 1917 to 20 in 1918.

Locally the bureaus have reorganized to the extent of changing from a township to a community unit organization. In each community at least one man is designated as a farm bureau committeeman. In the fifty-five counties there are approximately 2046 designated agricultural communities, with a total of 6101 appointed community committeemen.

Of particular interest is the appointment of a special agent, a Jew, to work among the non-English-speaking Jewish farmers, of whom there are large numbers in the State. This is the first definite provision to meet the needs of foreign-language farmers in this State.

Office of the State Leader of Home Demonstration Agents

By July 1, 1917, five counties had been organized with home demonstration agents. During the spring and summer of 1917, through cooperation with the New York State Food Supply Commission and the Federal Department of Agriculture, temporary agents were placed in thirty-six counties. On December 1 the work was reorganized, the State Food Commission taking supervision of the city work and the College taking the county work. Steps were at once taken to put the latter on a more permanent basis. An adequate expression of desire for a continuation of the work on the part of county women was first obtained, after which a representative, responsible, executive committee was elected, and community committees were appointed through which the agent could perfect and prosecute plans. The officers of the community committees form an advisory council which meets at least once a year to report and devise plans for the coming year.

Detailed reports of departments

A more detailed report of the activities of the departments of the College, as presented by the heads of those departments, follows.

FARM MANAGEMENT

G. F. Warren, Professor of Farm Management

The Department of Farm Management tabulated the state census of agriculture taken by the New York State Food Commission in 1917 and again in 1918. Many other States are this year taking a more or less complete census of agriculture by similar methods.

Much time has been devoted in the past year to work for the United States Food Administration, in collecting and tabulating data on the cost of producing milk.

The various agricultural and food authorities of the State and the Nation have called for much information on costs of production and other agricultural statistics.

Investigation.— The demands for preliminary data from the investigation work of the Department have been so numerous that the work has been seriously interfered with. Studies are being made of successful farms, and types of farming, costs of production, and farm layout are among the problems being investigated.

FARM CROPS

E. G. Montgomery, Professor of Farm Crops

In the fall of 1917 the Department of Vegetable Gardening was united with the Department of Farm Crops. It was deemed advisable, however, to continue work until the end of the fiscal year under separate budgets.

Due to the overcrowded condition of the Agronomy Building, the Department has been compelled to seek quarters elsewhere. Offices and laboratories are being prepared in the Poultry Building for the combined Departments of Farm Crops and Vegetable Gardening.

Changes in staff.— Acting Professor Paul Work, Superintendent of the Department of Vegetable Gardening, was drafted into the military service in September, 1917, and is now on leave of absence. R. G. Wiggans has returned to the Department of Farm Crops as instructor in charge of the field work, after a year spent on the teaching staff of Ohio State University. Robert Bier was appointed extension instructor in the Department of Vegetable Gardening on July 10, 1917. Albert E. Wilkinson, extension instructor, and A. E. Kenerson, instructor, in the Department of Vegetable Gardening, resigned on April 1, 1918, to enter commercial work. Assistant Professor E. L. Kirkpatrick, of the Department of Vegetable Gardening, resigned at the end of June, 1918, to take up demonstrative vegetable-drying work for the State of Colorado. No new appointments have been made to fill these vacancies, due to the present scarcity of men properly trained for such positions.

Extension in farm crops.— During the year the Department furnished a man for demonstration schools, giving work principally on pastures, forage crops, and culture of legumes. Approximately 3000 demonstrations have been carried on by the Department in cooperation with county agents.

For a number of years some attention has been given to the problem of providing better sources of seed. Four years ago local seed-potato-growing associations were started in a number of sections. Last year the Department started a seed-corn-growing association on Long Island. Due to the war emergency, certain other steps were taken last year. About sixty fields of wheat were inspected by Professor J. H. Barron, of this Department, as a source of seed. When the county agents gathered at the College in November for their annual meeting, this Department proposed that a "Better Seed Committee" be organized in each county, the function of these committees being not only to stimulate the production of home-grown seeds but also to supervise the selling and buying of seeds in cooperation with the farm bureaus. A seed survey was made by the Department in December as a part of the work of the Seed Stocks Committee.

Relation to organizations.— The Department has close relations with four state organizations — the New York State Potato Growers' Association, the Long Island Corn Growers' Association, the New York State Vegetable Growers' Association, and the Bean Growers' Association.

The New York State Potato Growers' Association resulted from the work of the potato survey begun by the Department in 1913. At present there are eight local affiliated associations, in the following counties: Franklin, Oswego, Cayuga, Onondaga, Suffolk, and Oneida. Last year approximately 75,000 bushels of certified seed was produced, most of which found a market at about fifty cents a bushel higher than the market price of commercial potatoes.

The Long Island Corn Growers' Association is located in Suffolk County. There were about sixty members in 1917. Professor Barron, of this Department, inspected their fields last fall and assisted in making the germination tests in December. The Association grew about 20,000 bushels of corn, about 12,000 bushels of which was considered as satisfactory seed.

For a number of years Acting Professor Paul Work has been Secretary of the New York State Vegetable Growers' Association. Since his departure for military service, it has been arranged that hereafter the secretary will be some one outside of the College, as most of the problems of the Association appear to be commercial problems of a type which the College cannot handle. There are, however, a number of educational problems, and the Department should keep in cooperation with the Association along educational lines. It has now been arranged to take up the work with local vegetable associations in cooperation with the farm bureaus in the State. It is probable that a large part of the extension work of the Department will be in cooperation with these local associations.

The Bean Growers' Association is an outgrowth of a meeting called by the Department in Farmers' Week in February, 1917. Another meeting was held in Farmers' Week in 1918, and steps were taken to form an organization. The final organization has recently been established. The lines of work to be carried out are not definitely decided upon, but the Association plans at least to keep in close touch with the bean laboratory of the College at Perry, New York. The first meeting of the Association was held at Perry on June 25, 1918.

Extension in vegetable crops.— During the past year A. E. Wilkinson has given his time largely to extension schools and public meetings in the interest of commercial and home gardening work. He also carried on considerable detail work with county agents in the use of fertilizer on cabbage and on muck land.

Robert Bier has given practically all of his time to home gardening activities since the first of January, working only with organizations since there was not time to give attention to special groups or individuals. The Department of Floriculture contributed the services of Professor White in this work. To reach the organizations in the most economical way a series of timely leaflets have been prepared, and these have been sent out every two or three weeks to a list of 600 persons.

In the cities and towns, Mr. Bier has given most of his time to following up the work and holding conferences with the leaders. The following brief statement of results covers the cities and villages with a population of over 5000 having leaders or supervisors; the larger cities may have two or more:

Number of cities	73
Number visited having leaders	57
Home garden leaders	38
School garden leaders	42
Leaders receiving federal aid	10
Leaders receiving state aid	?
Leaders receiving no recompense	?

As an illustration of how well the cities are taking to the home garden movement, surveys have been made in a few of the cities to determine the acreage planted. White Plains has 223.37 acres, Rome approximately 400 acres, Yonkers between 500 and 600 acres, and Scarsdale 71.83 acres, with other cities doing equally well. Planting has been doubled over last year in practically every case.

Surveys.— During the past year a bean survey of the State has been made by W. C. Jensen, who spent a part of the winter of 1917, and May and June of 1918, in the field. He has, however, been called to the army, and therefore will not be able to finish the work at the present time. A pasture survey was started two years ago in cooperation with the United States Bureau of Plant Industry. M. F. Abell, who had charge of the details, expected to finish the survey this summer and make a report. But he also was called to the army, and has placed the data on file in this office. It is probable that a report will not be made for some time.

Investigation.— W. C. Etheridge has completed his study of oats, and R. G. Wiggans is now in the third year of his study with the barleys. It is expected that as these collections are made and classified the Department will establish a permanent economic garden. The beginning will be made on such a garden this coming summer.

Owing to the lack of uniformity in the Department's fields, it has been found impossible to make careful tests. It has now been decided to develop a series of small plats eight feet square inclosed by rims. Artificial soil will be placed in these rims, which will be used for making careful and accurate tests. The plan is to start developing the work this year. The last Legislature appropriated $1000 for the purchase of land to be used for outlying experimental fields, and it is expected that these fields will be located during the summer.

Little work has been done with vegetable experiments, but at present there seems to be a demand for investigations on the development of muck lands, the packing of products for shipping, and the development of local seed growing.

FARM PRACTICE

J. L. Stone, Professor of Farm Practice

There were sixty-five students registered in the farm-practice course, thirty-eight of whom completed the work. This is about the same proportion as in the two preceding years. The records of the Department indicate that those who drop this course are very likely either not to return to the University or to change to some other college.

The work with the general winter-course students followed similar lines to those of previous seasons. An effort was made to adapt the teachings to the emergency conditions brought about by the war. The more important effect was to emphasize the teaching regarding the growing of the cereal grains for human food, and of the legumes, especially clover, for stock food.

The farming on the college domain does not vary greatly from that of last year. The present food emergency and the high price of stock feeds has led to added effort to utilize all available land, so far as possible, to increase the output of bread grains, and to grow as much as possible of leguminous forage, especially clover and alfalfa. The general rotation, followed with some variations, is corn, oats, wheat, hay. The effort is to have clover constitute as much as possible of the hay grown in these rotations.

Another attempt to increase production of wheat or rye and clover is to utilize as far as practicable the land not in our regular rotations in growing alternately winter grain and clover, thus making a two-years rotation with both crops emergency crops. The practicability of this has not yet been fully demonstrated. The present season's crop areas, not including the experimental areas of the various departments, are as follows:

Corn	59 acres
Oats	50
Wheat	67
Rye	7
Clover	31
Timothy and mixed	73
Alfalfa	30
Potatoes	2½
Roots	2
Oats and peas	8
Total	329½ acres

PLANT BREEDING

R. A. Emerson, Professor of Plant Breeding

Teaching.— The addition of Professor C. B. Hutchison to the staff of the Department in charge of teaching, and the consequent reorganization of courses, has materially strengthened the undergraduate instruction notwithstanding the decreased enrollment.

Investigation.— The investigations of the Department of Plant Breeding have been carried on without serious interruption, notwithstanding the loss of several graduate assistants. This has been possible in part because the lessened enrollment of students has allowed members of the teaching staff more time for research. It is the policy of the Department to maintain its more fundamental investigations with as little interruption as possible during the period of the war. In no other way, it is believed, can the Department contribute more to the readjustments that are likely to follow this critical period.

In addition to the genetic studies and practical breeding work already under way with corn, wheat, oats, potatoes, and timothy, studies of the inheritance of various characters in flax and barley have been begun during the year. In cooperation with Professor M. F. Barrus, of the Department of Plant Pathology, an investigation of the mode of inheritance of resistance to anthracnose in beans has been inaugurated. The production of disease-resistant strains of field beans carried on during the past year by means of a special appropriation gives promise of early results.

Extension.— With the addition of F. P. Bussell to the departmental staff in charge of extension work, the extension activities of the Department have been materially increased. While considerable instruction in plant breeding has been given in extension schools, the principal lines of work have been: (1) the distribution to farmers of the State of improved strains of crops produced in connection with the experimental work of the Department; and (2) the helping of farmers to start breeding work on their own farms. In connection with the latter, numerous field meetings and demonstrations have been held. Instead of attempting to get a large number of farmers in any community to undertake breeding work on a small scale with several crops — work which could not well be followed up by the extension specialists — it is rather the policy of the Department to help one or two men of the community to carry out thoroughgoing work with one or two crops of importance in a particular region, with the idea that these men will be able ultimately to furnish select seed to their neighbors. Work of this sort with associations growing seed for other parts of the State is of particular importance.

BOTANY

K. M. Wiegand, Professor of Botany

Teaching.— The Department of Botany has for some years devoted special attention to the acquirement of teaching materials. During the current year the departmental herbarium has made substantial growth. The accessions include, among numerous smaller collections, a set of Newfoundland plants collected by Messrs. Fernald and Wiegand in 1910–11 and donated by the Gray Herbarium (2400 sheets); a set of northern New York State plants collected by Mrs. Orra P. Phelps, received from the Gray Herbarium in exchange (1450 sheets); a set of plants from Wellesley, Massachusetts, collected by Professor Wiegand and donated by Wellesley College (400 sheets); a set of rare plants sent out by the Gray Herbarium (200 sheets); plants collected in 1917 in New Jersey, on Staten Island, and on Long Island, by a member of the departmental staff, A. Gershoy (1000 sheets); and local specimens collected about Ithaca by members of the staff in 1917 (1800 sheets) — making a total of more than 7000 sheets added to the herbarium during the year.

Heretofore the introductory course in botany, course 1, has been an alternate requirement with Zoology 1, in the sophomore year. By action of the faculty it was this year made a requirement for all students and placed in the freshman year.

Staff.— The following promotions have been made in the staff of the Department: J. R. Schramm, promoted to Professor; O. F. Curtis, promoted to Assistant Professor. The staff as now organized consists of three professors, three assistant professors, eight instructors, and eight assistants.

Investigation.— All members of the teaching staff, as well as all major graduate students, are engaged in some research. This work is progressing satisfactorily. Some of it will be ready for publication during the coming year. Thirteen titles are reported from the Laboratory of Plant Physiology, and twenty-one titles from other laboratories of the Department.

Extension.— The extension work of the Department has been confined, as in the past, to three lines of work as follows:

1. Correspondence with farmers and others in regard to weed identification, weed eradication, legume inoculation, and other matters. There were 193 letters sent out relating to weeds, and 2500 relating to inoculation.
2. Distribution of cultures containing the organisms for inoculating soil in preparation for legume crops. The number of these sent out was 7500.
3. Lectures and demonstrations. A lecture on legume inoculation was given, and an exhibit and demonstration was held, during Farmers' Week.

Publications.— Publications of the Department aside from those issued by the University, which are listed elsewhere, are as follows:

Some species and varieties of Elymus in eastern North America. By K. M. Wiegand. Rhodora, vol. 20, p. 81.

A new variety of Triosteum aurantiacum. By K. M. Wiegand. Rhodora, vol. 20, p. 116.

The development of some exogenous species of agarics. By Miss G. E. Douglas. American Journal of Botany, vol. 5, p. 36.

Recommendations.— Provision should be made for the appointment of at least one more assistant professor of plant physiology. A large proportion of the problems in the applied sciences are primarily physiological problems. The field for research is therefore very large, and there is great need that many of these problems should be investigated. There is also considerable demand for additional courses in plant physiology. The staff is so heavily burdened with teaching and extension work that it has not been possible to give the additional courses needed, nor have the members had time to conduct research which they are so anxious and well qualified to perform. Even if no additional courses were given, the demand for research and the large number of graduate students registered would indicate the need of an increase in the number of professors.

PLANT PATHOLOGY

H. H. Whetzel, Professor of Plant Pathology

Investigation.— Research by members of the staff of the Department of Plant Pathology has been curtailed to some extent because of pressing work in connection with food conservation. As much work as possible has been continued, however, since the solution of problems in plant pathology usually contributes to a better understanding of disease control and for that reason contributes to the general conservation movement.

Beans are subject to a number of diseases which are very seriously reducing the yield of this important crop. A hybrid bean having all the qualities of white marrow and possessing resistance to the anthracnose disease has been developed. A study of disease inheritance in beans is being made in cooperation with the Department of Plant Breeding. Bean root rot is being studied intensively under a special legislative grant made for the purpose. The development of resistant strains seems to offer the most promising method of controlling this disease, and the work has been directed along these lines. This work is also done in cooperation with the Department of Plant Breeding. Bean mosaic, a baffling disease, has been studied, but as yet little is known of the nature of the disease and nothing of its cause.

The first phase of the investigation of potato leaf roll, a study of the normal histology of the potato plant, has been completed and is ready for publication. Work on the morbid anatomy and histology is nearing completion.

Aside from the work on bean mosaic, much energy has been devoted to a solution of the problem of the etiology of mosaic diseases generally, of which there are a large number. No important discoveries have been made. Included here are peach yellows, cucumber mosaic, potato mosaic, and the mosaic diseases of a large number of other plants.

Various vegetable diseases have been studied in cooperation with Rochester University and with the vegetable growers of Williamson. The former work has been discontinued temporarily by the withdrawal of Professor Jagger to engage in special work for the United States Department of Agriculture.

Work on the crown canker of roses has been continued. Experiments for the control of rose mildew and black spot have been very successful.

A number of little-known diseases of cereals and forage grasses are receiving attention. Excellent progress has been made on two of these. Experiments looking to better methods of control of some of the important diseases of cereals are under way.

Experiments are under way to determine the relation of the health of plants to their susceptibility to disease. Other experiments are in progress, under controlled conditions, to determine under what circumstances fungous parasites gain entrance to their host. The effects of various sets of conditions on the development and progress of diseases is also being studied.

A number of mycological problems are being studied. The most notable of these is a taxonomic study of the genus Botrytis and of the family Coryneliaceae. The life history of a parasitic Eocronartium has been completed.

Extension.— The extension work of the Department can be classified into two groups as regards source of funds — the regular extension work conducted under the Smith-Lever project, and the emergency work conducted for the New York State Food Supply Commission during the period from May 1 to September 30, 1917. Aside from correspondence regarding various diseases and their control, work under one or the other or both classes has been directed toward carrying out the following projects: control of potato diseases; control of fruit diseases; control of cereal smuts; control of diseases of other crops; plant-disease survey; exhibits; extension schools and farmers' institutes. The work on these disease control projects has been conducted largely by demonstrations on the farm or in demonstration cars; by lectures at various meetings of farmers; by farm visits; by the employment of field assistants in disease and insect-pest control, who were located in the county for the special purpose of giving accurate and timely information regarding control measures; and by propaganda to convince farmers of the desirability of adopting such measures.

Demonstrations in the control of potato diseases, on potato cars or at farm bureau meetings, were held in seventy-eight localities, representing thirteen counties. Under the New York State Food Supply Commission, inspection of potato fields in order to secure good seed for 1918 was made by two inspectors in thirteen counties, and as a result 923 acres of potatoes good enough to pass two inspections were located and listed. Seven county field assistants were placed in eight counties, with the result that over 5100 acres of potatoes were sprayed more properly than could have been done without this service.

Fourteen demonstrations in the control of fruit diseases were held in seven counties. Nine counties had field assistants receiving supervision from this Department. Five of these assistants were hired on funds of the State Food Supply Commission, and the others from various other funds. Eleven of the important fruit counties received some assistance from this Department.

Twenty-nine demonstrations in the control of oat smut were held in five counties. In addition, two counties had the services of two federal demonstrators working in cooperation with the College of Agriculture, by whom twenty-five demonstrations for the control of wheat smut were given.

Fourteen lectures, inspections, or demonstrations in the control of diseases of other crops were held in twelve counties.

Fifty-two persons, from forty-five counties of the State, reported plant-disease conditions in their counties or communities to this Department, where the results were tabulated and the information was made available. By means of this survey the Department was able to determine the earliest appearance, distribution, and severity of the various plant diseases, and to direct control work accordingly. This work was done in cooperation with the Plant Disease Survey of the United States Department of Agriculture.

Six exhibits at state and county fairs, at state fruit meetings, and at the Rochester Exposition, were made during 1917. In addition to these a potato-disease exhibit was carried on the potato car.

Work was given at thirteen extension schools, representing eleven counties.

In addition to four persons regularly employed in extension activities, eight members of the staff assisted in some regular work. The State Food Supply Commission employed thirteen field assistants, two potato inspectors, and one stenographer from the Department, for plant-disease and insect-pest control work. The United States Department of Agriculture employed two persons for the plant-disease survey and two for wheat-smut demonstrations. Various other institutions, departments, corporations, and individuals cooperated by participating in the expense of the work.

Needs of the Department.— The Department is not satisfactorily housed. This has never been more apparent than during the past cold, dark winter. The light, needed for microscopic work, is very weak, practically necessitating the use of artificial light most of the time. The low temperature was unavoidable, but low temperature in a basement is not conducive to good health.

There has been a steady demand for investigation of the low-temperature conditions of cold-storage warehouses in relation to the decay of fruits and vegetables. Fundamental work should be done first, but there are no facilities in the Department for such work. The initial expense of proper equipment would be moderately large, but the number of important investigations awaiting such facilities justifies the installation of such equipment. Much of the apparatus could be used to advantage in a study of the relation of conditions in packing houses and refrigerator cars to the decay of fruits and vegetables in transit and on the market.

The value of plant-disease experts to assist county agents during the growing season has been fully established, and definite funds to finance this work should be made available for next year.

SOIL TECHNOLOGY

T. Lyttleton Lyon, Professor of Soil Technology

Teaching.— In the Department of Soil Technology a course in soil bacteriology was given this year for the first time. It is a two-hours course consisting chiefly of laboratory work, and requires as prerequisites general bacteriology and certain courses in soil technology. The instruction was given by Dr. J. K. Wilson.

Investigation under the Adams fund.— Work under the Adams fund is embraced in one project — a study of the availability and utilization of plant nutrients in soils under different methods of treatment.

Data covering the experiments of the first five years with twelve lysimeter tanks have been compiled and interpreted. These tanks were filled with Dunkirk clay loam soil, each tank holding about 3½ tons. The soil in certain of the tanks received an application of lime at the beginning of the experiment, and an annual application of sulfate of potash was administered to the soil in two tanks. As there was no protection from the weather the natural rainfall was allowed to fall upon and percolate through the soil, and the percolate was collected, measured, and analyzed. Crops were grown each year in some of the tanks, and others were kept bare of vegetation all the time.

The average annual rainfall for the five years was 31.14 inches, of which 24.40 inches, or 78.35 per cent, percolated through the unplanted soil and 16.96 inches, or 54.46 per cent, through the cropped soil. Thus about one-fourth of the rainfall was utilized by the plants. The average evapo-transpiration ratio for the cropped soil was 1:580, the crops being maize, oats, timothy, clover, and mixed grasses. The average minimum transpiration ratio for the same crops was 1:290. The minimum transpiration ratio was least for maize and greatest for the grasses, while oats were intermediate.

Although the crops were large, amounting in the case of maize to over one hundred bushels of grain to the acre, there was never a deficiency of moisture in the soil, which illustrates the great water-holding capacity of a well-drained soil.

The data on the nitrogen removed in crops and by drainage water appear to support the idea that certain kinds of higher plants have a depressing influence on the production of nitrates in soil.

Cropping the soil resulted in a conservation of calcium as compared with leaving the soil bare, as shown by the fact that the drainage water from the unplanted soil contained 180 pounds more calcium per acre than did the crops and drainage water combined from the planted soil. The greater removal of calcium from the unplanted soil was due in part to the larger quantity of nitric acid in the drainage of this soil, and in part to a greater removal as bicarbonate.

Concerning the question as to the effect of applications of calcium on the liberation of soil potassium, the data indicate that in this soil there was no such substitution. On the other hand, applications of potassium sulfate markedly increased the removal of calcium and to a less extent that of magnesium.

The removal of sulfur in the drainage water was from three to six times as great as in the crops. There was as much carried off by the drainage water from the unplanted soil as by both drainage water and crops from the planted soil. The application of lime was accompanied by an increase in the quantity of sulfur in the drainage water. Of the sulfur added annually to the soil in the form of potassium sulfate, more than one-half was removed in the drainage.

Investigation under the Hatch fund.— There is one project under the Hatch fund, the designation of which is " The composition and properties of certain soil types and the effect of some plants when grown on them."

An experiment in fertilizing a six-years rotation of crops has reached the end of its first rotation. The essential feature of this is a comparison of the practices of supplying farm manure or commercial fertilizers to the hay crops in a rotation, as compared with the practice of applying these substances to the grain crops. The rotation consisted of timothy three years, followed by corn, oats, and wheat. The soil on which the experiment was conducted is particularly well adapted to the production of timothy, somewhat less so to the growth of small grains, and poorly suited to corn. The experiment, therefore, is of concern to farmers on natural grass land where timothy is the leading crop, and is not necessarily applicable to other soils and types of farming.

As between the practices named, that of applying farm manure or commercial fertilizer to the hay crops proved to be decidedly preferable. Not only did the crops respond to this plan of fertilization in the year in which the fertilizer was applied, but also the treatment resulted in an increased yield of one or two of the following cereal crops, due apparently to plowing under more organic matter in the form of sod.

Response to fertilization applied directly to the grain crops was not sufficient to justify the use of more than very small applications of fertilizer. On the type of soil used in the experiment it appears to be unprofitable to use fertilizer on the cereal crops.

Soil surveys.— Two areas, Saratoga County and Oswego County, were surveyed in the field season of 1917. These have an aggregate area of 1799 square miles. These counties constitute the twenty-fifth and twenty-sixth areas surveyed. The total area now covered by surveys is 17,113 square miles. The reports on the above-mentioned counties will be the eighth and ninth published by this College, the earlier reports having been published only by the United States Department of Agriculture, with which this College cooperates in the conduct of soil surveys. As a result of these surveys, coupled with supplementary investigations, the Department now has a fairly thorough knowledge of soil conditions in all sections of the State.

Extension.— The extension work in soils is each year becoming more crystallized along definite lines of effort. Methods of procedure are being standardized. All work in soils is grouped under Smith-Lever Extension Project No. 11. For purposes of brevity, the several activities are tabulated in the following form:

Topic	Number during the year
Field demonstrations	
Drainage — Farms visited	146
Power ditching machines	4
Rods of trench dug by machines	12,333
Lime — in 20 counties, 1917	235
Fertilizer — in 20 counties, 1917	47
Maintenance of organic matter	9

Topic	Number during the year
Demonstration schools	
Number attended	22
Half days instruction given	138
Number of schools receiving full week instruction	7
Special lectures — Number	44
Attendance	2,850
Special visits to farms	51
Farm bureau counties visited	17
Correspondence — Letters written	4,006
Form letters	13
Circulation	1,008
Samples of soil examined	67
Soil acidity outfits sent out	44
Fertilizer outfits sent out	10

Of the field demonstrations the drainage work is now the most active, and shows the cumulative effect of the attention that has been given to the subject by the departmental extension staff over a period of several years. The most significant development is the introduction of the engine power trenching machines, which are being financed by the State Food Commission. Three machines were purchased by that organization in 1917 and were set at work in the counties of Tompkins, Ontario, and Orleans. They began work on September 1 and closed the season on December 6. They are operated under the general administrative direction of the farm bureau in each county, working in cooperation with this Department and with the Department of Rural Engineering. The success of the first three machines led the Food Commission to purchase ten additional machines. A conservative estimate of the number of rods of trench such a machine may construct in a field season is 8000. On this basis the thirteen state-operated machines should construct about 300 miles of drainage trench in a season. Results indicate that the increase in crops will be from 50 to 75 per cent over a large part of the area so drained. In many cases it will make the difference between no crop and a good crop. Consequently, this work is a large contribution to the food supply of the State, and it comes with such promptness and surety as to contribute to the current season's supply of food.

The practice of using lime is growing rapidly and the main problem now is to provide adequate means of distribution and local storage against the time when the farmer can haul and apply the material. In the southern tier of counties the field demonstrations show increase in the yield of hay, from the use of one ton of limestone, ranging from 1000 to 3599 pounds per acre. This increase is carried through the rotation.

Fertilizer demonstrations have been largely confined to the use of acid phosphate, with other methods of soil improvement. The shortage in fertilizer materials has intensified interest in substitutes for the standard fertilizer materials of normal times.

The correspondence has shown a large increase and reflects the increased interest in questions of food production and soil improvement.

Publications.— Publications of the Department aside from those issued by the University, which are listed elsewhere, are as follows:

Size of plots for field experiments with soils. By T. L. Lyon. Journal of the American Society of Agronomy, vol. 9, p. 405–410.

The effect of certain factors on the carbon dioxide content of soil air. By J. A. Bizzell and T. L. Lyon. Journal of the American Society of Agronomy, vol. 10, p. 97–112.

Soils and fertilizers. By T. L. Lyon. Textbook. 255 p.

Top-dressing meadows with commercial fertilizer and manure. By E. O. Fippin. Country Gentleman, March, 1917, p. 6.

Lime for Chautauqua county soils. By E. O. Fippin. Chautauqua County Farm Bureau News, January, 1918, p. 3–4.

Open ditch drainage. By E. O. Fippin. Country Gentleman, December 8, 1917, p. 8.

Tile drainage in Ontario County. By E. O. Fippin. Ontario County Farm Bureau News, April, 1918, p. 1.

Soils, their properties and management, Chapters 1, 2, 3, 4, and 17. By E. O. Fippin. Farm Knowledge, April, 1918, p. 5–16, 17–30, 31–57, 58–65, 402–409.

Recommendations.— For many years analyses of soils from different parts of the State have been made. In spite of this the College has no systematic knowledge of the composition of these soils, because the samples were not taken by persons who understood soil sampling and the importance of recording the exact location so that the samples could be referred to the series and types to which they belonged. If the samples were properly taken the College would gradually be provided with sufficient knowledge of the soils of the surveyed areas of the State to make unnecessary complete analyses of miscellaneous samples sent in by farmers.

While some progress has been made in providing for the experiment fields to be located in the important agricultural regions of the State, the latest Legislature did not make a sufficiently large appropriation to enable the Department to begin work on even one field. Efforts to get enough money to provide for the equipment and operation of at least two fields should be continued.

A frame structure, with wire netting sides and concrete floor, is needed at the experiment field for use in storing crops from the experiment plats before they are threshed. It should also have a projecting roof to cover the concrete threshing floor, which is now unprotected from the rain. Such a building would cost not less than $2000.

Two additional men are needed in the extension work of the Department. One of these would devote his time to drainage work of the same nature as that now done by Professor Warsaw, for whose services there is such a great demand that he can meet but a small proportion of the calls. The other extension man would be engaged with the farm bureau demonstration work, which calls for a visit to each of the counties two or three times in the course of the year to attend demonstration meetings and go over the county problems. Both these men should be experienced in their fields of work.

POMOLOGY

W. H. Chandler, Professor of Pomology

Investigation.— Few of the investigations under way in the Department of Pomology are of such a nature that they can be finished within a few years. The experiments in pruning old and young trees, hardiness studies, fertilizers for strawberries and bush fruits, osmotic relationship and incipient drying of fruit, color of fruits, and factors that influence the setting of fruit, have been continued. Under hardiness studies an effort is being made to get over the entire State and into other States to learn the effect of the past severe winter on the various fruit varieties and species.

Extension.— The extension division has participated in the following activities during the past year:

Lectures — Number		81
	Attendance	3,656
Demonstrations — Number		88
	Attendance	1,678
Conferences — Number		346
	Attendance	748
Conventions		13
Farm visits		75

The following extension activities are being continued: a demonstration of the methods whereby an old and neglected orchard may be renewed profitably, at Port Byron; and a demonstration of the value of different combinations of fertilizers for the peach orchard, at Pultneyville. In addition, the Department is working in cooperation with the Niagara County Farm Bureau in establishing central packing houses.

FLORICULTURE

E. A. White, Professor of Floriculture

In September, 1917, the Department of Floriculture received the donation of a valuable collection of exotics from the estate of Charles Seymour Husted, of Broadalbin and Brooklyn, New York. This collection will be of much value in furnishing illustrative material for teaching purposes, especially in courses in conservatory plants.

The recent ruling of the United States Fuel Administrator that during the coming winter greenhouses shall receive but fifty per cent of the fuel consumed last year, will make the work of the Department this year more difficult. The members of the Department feel, however, that the hardship will be less keen in this institution than to private individuals engaged in commercial floriculture, and that the Department should make no claims for exemption but should comply with the ruling. It is therefore expected to close part of the range of glasshouses during the coming winter.

On July 1, 1917, M. E. Farnham was appointed instructor in floriculture. He has devoted his entire time to work of an investigative nature. Since his appointment, however, he has come within the draft age and has been placed in Class I; he has therefore resigned, his resignation to take effect July 1, 1918. On January 1, 1918, E. C. Volz, instructor in floriculture, resigned to accept an appointment as director of home gardens in Michigan. Because of the somewhat reduced registration of students in the Department due to the conditions of the war, and because of the scarcity of desirable men, a request for filling these vacancies will not be made during the period of the war unless conditions in the Department seem to demand it.

Last February, as a war measure, a request came from the Departments of Rural Education and Vegetable Gardening, and from the States Relations Service of the Federal Government, for assistance in developing home and school garden projects. In response to this request, Professor White, of this Department, has spent the major part of his time since March 1, 1918, in visiting school superintendents in western New York and in organizing the work in school and home gardens.

Owing to the shortage of labor existing since the outbreak of the war, it has been possible to keep up work only on those projects in investigation involving perennial plants, with the exception of some indoor studies on sweet peas.

Rose test garden.— In the rose test garden, valuable notes have been taken on the hardiness and adaptability of varieties.

The additions to the rose garden this year are few in number, and consist chiefly of climbing varieties since the Department has not been in a position to take care of plants of the bush varieties. The land added to the garden has been leveled, ready for seeding the lawn, but this work will be delayed until the drains can be put in.

The severity of the past winter killed some varieties of roses and destroyed some plants of other varieties, but on the whole the roses stood the test very well. It is thought that the past winter can be regarded as the supreme test, and that those varieties which came through can be confidently recommended for New York conditions.

The garden attracted many visitors this year and it is noted that the number of visitors increases each year as the garden becomes better known. The Auburn and Syracuse Rose Societies visited the garden this year. During the period of greatest bloom, visitors are almost constantly in the garden admiring the flowers.

Peonies.— Although the main purpose of the peony plantation was fulfilled some time ago, a large number of varieties have since appeared in the market. An effort was made last fall to add these to the Department's collection, with the result that sixty-six varieties were procured. It is purposed to keep the collection as complete as possible. With the exception of the roses, the peonies attract more visitors than any other flower grown at the Craig gardens.

Sweet pea and gladiolus studies.— The study of the garden varieties of sweet peas has been discontinued, for reasons mentioned earlier. The study of the winter-flowering varieties was carried on in the college greenhouses last winter. Eighty-six varieties were grown and described. This completes another stage of the sweet pea studies, and a publication of the results is planned. The gladiolus investigations have been given up altogether, except that such varieties as are sent by the Gladiolus Society unsolicited are grown and notes are made on them. The Department is looking forward to the time when this work may again be properly taken care of, for there is a sincere desire on the part of the American Sweet Pea and American Gladiolus Societies that the work shall be carried on here.

Phlox studies.— The phlox collection has been increased by the addition of many new varieties. Many data have been compiled and will be published at a later date.

Iris studies.— As stated in previous reports, a large collection of iris has been gathered and planted. Last year the plants were lifted, but, owing to the extremely wet soil, they could not be planted last fall. They were heeled in and came through the winter in good condition for planting this spring. A new site has been chosen between the peony plantation and the rose garden, where the irises will doubtless receive much attention from visitors.

FORESTRY

Ralph S. Hosmer, Professor of Forestry

Faculty.— Professor A. B. Recknagel, of the Department of Forestry, was granted leave of absence from the University for the fiscal year 1917–18, to permit him to act as Forester and Secretary of the Empire State Forest Products Association, the centralized organization of the lumbermen of New York State. During the year Professor Recknagel has had opportunity to acquire much new and intimate information concerning the forests of the State, which will be of high value to the Department.

In the summer term of 1917, Professor Ralph C. Bryant, of the Yale School of Forestry, conducted the courses usually given by Professor

Recknagel. In the autumn Professors Spring and Bentley, during their vacation period from Cornell, taught in the Yale School of Forestry. This exchange of professors between these two schools of forestry is significant as being indicative of close correlation of work and of interests.

On October 1, 1917, Bernard A. Chandler, formerly Assistant State Forester of Vermont, was appointed Assistant Professor of Forest Utilization for the period of the college year. In May, 1918, he was made a regular member of the staff. He has since been engaged primarily in forest investigation work, mainly in the Adirondacks.

On December 31, 1917, Cedric H. Guise resigned as extension instructor in forestry to enter the United States School of Military Aviation at Ithaca, where he is now serving as instructor in the use of instruments and in mapping.

In June, 1918, Assistant Professor John Bentley, jr., was promoted to a full professorship, with the title Professor of Forest Engineering.

Teaching.— The number of students registered in the courses offered, as compared with previous years, was as follows:

Year	Registration in courses intended primarily for students from other departments	Registration in courses intended for both professional students and those from other departments	Registration in professional forestry courses	Registration in graduate courses	Total number of students registered in regular courses	Winter course	Summer school	Grand total
1912–13	213	56	143	....	412	47	22	481
1913–14	139	80	131	40	390	57	28	475
1914–15	115	107	214	52	488	20	18	526
1915–16	300	196	189	33	718	17	.....*	735
1916–17	279	186	215	32	712	36	.....*	748
1917–18	99	69	61	8	237	10	3	250

* In place of regular courses during the Summer Session there was given, both in 1916 and in 1917, a series of public lectures on forestry.

Owing to the large number of enlistments in war service from among the professional forestry students during the spring and summer of 1917, the actual number of professional forestry students, excluding freshmen, stands at 30 for 1917–18 as against 81 in 1916–17.

During the year 1917–18 five graduate students have been registered in the Department. Two of these men received the degree of master in forestry this year. One man, a candidate for the degree of master of science, passed his examination in June and will receive his degree in September.

It is the judgment of the departmental staff that in the period following the war the need for technically educated foresters will unquestionably be great. Consequently the Department is prepared to continue to train professional students, as well as to give instruction to those from other departments or colleges who desire an understanding of the basic principles of forestry.

Investigation.— The appointment of Assistant Professor Chandler made possible the carrying into effect of a part of the program of the Department in forest investigation. Two problems were attacked — a study of hardwood utilization in the Adirondacks, and the collection of data bearing on the growth of red pine. Both studies will need to be continued for some time, but certain conclusions are already in hand. A preliminary report is now in preparation which sets forth the general situation as regards the utilization of Adirondack hardwoods. The study as a whole is designed to determine how large a proportion of the timber crop is marketable economically under any given set of conditions. In this three main points are involved: (1) the quantity and grades of material now being left in the woods; (2) the value of this material for manufacturing purposes; and (3) the cost of delivery and manufacture. Both the hardwood and the red pine study will be continued during the summer of 1918.

During the months of May and June Professor Chandler was detailed to assist in a cooperative study of the important forest types in the Adirondacks, including the establishment of permanent sample plots which will serve also as demonstration areas. This work is being carried on under the direction of a committee of the New York Section of the Society of American Foresters, of which Professor S. N. Spring is chairman.

Extension.— Starting in January, 1918, Assistant Professor Collingwood, and also for a few weeks Assistant Professor Chandler, devoted no little time to the wood fuel campaign, in cooperation with the State Advisory Committee on Wood Fuel appointed by the Conservation Commissioner, at the direction of the Governor, to work in conjunction with the State and County Fuel Administrators. Professor Hosmer was named as one member of this committee, and Professor Collingwood was given charge of one of the districts into which the State was divided in the campaign, a forester being assigned to each district. Especial emphasis was placed in this work on the establishment of municipal wood yards and the increased use of wood as a substitute for coal.

In cooperation with the New York State Food Commission, a bulletin entitled *Maple Sirup and Sugar Production*, by Professor Chandler, was issued in the spring.

Twenty-one woodlots were examined for the purpose of giving advice regarding the future management of the property, to estimate the timber, or to assist the owner in marking the timber preparatory to cutting.

Inspections of work previously done, or preparatory to work which is planned for the future, were made in sixteen cases. Coupled with these were eight conferences with county agents. During the winter and spring eighteen conferences were held with county fuel administrators and others interested in promoting the greater use of wood as fuel. Twenty-four lectures were given, with a total attendance of 1597—three of these being given in connection with farm demonstration schools. A total of 618 letters were written to persons within the State on subjects relative to forestry.

Recommendations.— It is the belief of the departmental staff that the most important need in forestry at present is in the line of investigation, particularly in the branches of forest utilization and silviculture. The appointment of Assistant Professor Chandler last October, together with his work during the year, constitutes a decided step in advance for this Department, but it also emphasizes more clearly the extent of the field. Particularly in silviculture is the necessity most pressing for a better knowledge of our important timber trees, their life histories, and the laws governing their growth and development.

Much of this character of study could best be carried out on a forest tract of a few thousand acres, under the exclusive control of the College. During war times retrenchment rather than expansion must of necessity be the motto, but the need for a college forest for experiment and demonstration should not be forgotten.

In the meantime, as a part of the Cornell experiment station work, there is ample opportunity in the State for the prosecution of investigations that could not but yield results of the greatest technical value, and often as well lead to direct practical improvements in existing methods. To obtain some of the data that are most essential requires the use of instruments of precision. One need of the Department is for this class of equipment. Another need is for a man to attack the problems in silviculture, after the manner in which the Department has begun this year to work out those in forest utilization.

ENTOMOLOGY

J. G. Needham, Professor of Entomology and Limnology

Teaching.— Of the thirty-nine courses offered by the Department of Entomology in its various lines, all have been given save one. The course in beekeeping has been abandoned for the period of the war because the only person on the staff qualified to give it, Professor E. R. King, has entered the United States Aviation Service.

Thirty-six graduate students have been registered for work in the Department during some part of the year. Many of these have now entered military service.

The work of teaching has been increasingly difficult, due to the natural unrest among the students consequent upon the progress of the war and also to the loss of a very large number of the younger teachers and the assumption of their work to a considerable degree by those who remain. Of the twelve men who began the work of the year as graduate assistants, but two now remain. One has been replaced by a young woman, and one by a man who is still an undergraduate, men of the usual qualifications being no longer available.

Investigation.— Conditions have become equally unfavorable for research, except of the sort that is directed toward immediately practical ends. Yet a considerable amount of good work is being done by graduate students and a very creditable collection of research papers has been published during the year. Noteworthy among these is Dr. W. D. Funkhouser's *Biology of the Membracidae of the Cayuga Lake Basin*, published as a memoir of the agricultural experiment station. Most of the young men who have entered their country's service have temporarily abandoned important research work to which they were thoroughly committed. Numerous outside more or less public duties growing out of the war have greatly limited the always meager opportunities for research on the part of older members of the staff.

Extension.— The extension side of the Department's work is being pushed with more than usual vigor. The food shortage has made a heavy demand for all the aid that can be rendered in the way of protecting crops from insect pests. However, with the utmost effort the Department will not be able to do what it should, for lack of trained men.

Recommendations.— In this time of war but a single recommendation is offered — the establishment of the fish-cultural experiment station which has long been a part of the Department's plans. This is as much a war measure as any other measure having to do with increasing the food supply. When the supply of animal food is so short, it is surely a good time to remember the following facts:

1. The amount of fish in the country can be increased more rapidly than that of almost any other animal food.

2. Unlike hogs and chickens, fishes are not direct competitors with man for food. They feed on stuffs that man cannot use.

3. The fish crop can be raised without displacing another crop because the areas needed are now unproductive.

4. The fish crop may be expanded indefinitely, since there are extensive waste wet lands whose utilization in pond culture would bring into human service the most neglected of all our natural resources.

DAIRY INDUSTRY

W. A. Stocking, Professor of Dairy Industry

Teaching.— All the regular courses were given by the Department of Dairy Industry in 1917-18, even though the staff was smaller than usual due to the fact that a number of the members were engaged in war work.

Because of the scarcity of persons trained in dairy work, the Department offered a two-weeks emergency course from June 12 to June 25. The purpose of the course was to train both men and women to operate the Babcock test, in order that they might be available for positions in dairy plants, cow-testing associations, and advanced registry work, to replace more experienced men who have been called either by the draft or by other lines of industry. Seventeen men and two women took this course.

For a number of years the Department has handled large quantities of dairy products in order to have these materials for laboratory instruction purposes. Last summer, because of the war situation and the unusual conditions that developed in the dairy industry, it became impossible for the Department to compete with milk shipping stations and milk condensaries and manufacture its milk into butter and cheese. Since the Department had no equipment for making condensed or powdered milk, it was obliged to turn over its milk supply to the Ithaca Condensary. While the Department has handled small quantities of products during the year in connection with its teaching work, it feels that its teaching has been handicapped because of the loss of this work. It is hoped, however, that these conditions are only temporary.

Investigation.— The smaller registration of students during the year has given the members of the teaching staff a little more time than formerly for research work. Each member of the staff has conducted research in his particular line of work.

Extension.— At the beginning of the year G. Clayton Dutton was added to the departmental staff as an extension instructor, primarily in cheese work. Mr. Dutton was for many years a practical cheese maker, and for a number of years he was an instructor in the State Department of Agriculture and assisted in the instruction in cheese work at the College during the winter course.

During the year there has been a special demand for help in connection with dairy plants owned by farmers throughout the State. W. E. Ayres, of this Department, has given assistance in the preparation of plans and the selection of equipment for a number of such plants.

Special work.— Last summer the Federal Government called on all the men of this Department, except the head, to do special emergency work or to inspect navy butter. The Government has already called on the entire staff of this Department for similar work during the coming summer. It is of interest to note that for the past several years the Government has drawn more than fifty per cent of its navy butter inspectors from this Department.

Recommendations.— The recommendations made last year for increased facilities in carrying on the work of the Department are renewed. These facilities are especially urgent at the present time in order that the changed conditions resulting from the war may be met. The normal relationship existing between market milk and condensed milk on the one hand, and butter and cheese on the other, has been upset, making more important than ever the giving of instruction in the manufacture of condensed and powdered milk. The Department should also be equipped for the manufacture of such by-products as casein, milk sugar, and albumin. The cheese work in the Department also should be extended to include a variety of fancy cheeses which it is not now possible to make.

There is urgent need of a suitable ice house for the storage of ice for the Department.

ANIMAL HUSBANDRY

H. H. Wing, Professor of Animal Husbandry

Investigations in the Department of Animal Husbandry have continued during the past year along the lines of animal nutrition, animal breeding, and the keeping of records in addition to those that have been in progress for the past several years. An extensive study of color inheritance in guinea pigs has been made, the results of which are practically ready for publication.

POULTRY HUSBANDRY

J. E. Rice, Professor of Poultry Husbandry

The large reduction in the number of students registered in the Department of Poultry Husbandry, the many changes in the personnel of the staff, the increase in the demand on the part of poultry producers for assistance, the very unfavorable season for crop production, and a large increase in the general cost of maintenance due to the war, are the striking conditions of the year in this Department.

The value of the property under the direct responsibility of the Department is as follows:

Buildings	$118,000.00
Stock	3,588.50
Equipment and appliances	26,734.34
Land	19,775.00
Supplies	754.69
Total	$168,852.53

The number of varieties in each branch of the poultry stock is as follows: fowls, 39; geese, 3; ducks, 6; pigeons, 4; pheasants, 2; grouse, 1; quail, 1; birds on game farm, 250.

Of the total number of fowls, 329 were used for teaching purposes and 1598 for research.

Teaching.— The decrease in teaching activities is shown in the following summary for the years 1916 and 1917. It is seen that there has been a reduction of approximately fifty per cent.

	Registration	
	1916	1917
Third term	74	29
Summer session	15	16
First term	247	101
Winter course	364	123
Second term	361	194
	1,061	463
Graduate students	7	7

Extension.— All the members of the staff, except those whose work made it impossible for them to leave town, participated in some form of extension activity. As a result a very much larger amount of extension work was accomplished than in the preceding year. There were 357 extension engagements filled, at which 19,140 persons were present. Particular stress was placed on farm visits and especially on the selection of stock in an attempt to save the poultry industry. The selection campaign, it is estimated, resulted in the discarding of over 300,000 unprofitable fowls, thus saving not less than 936 tons of feed (amounting to $56,160) which was thus released for profitable production purposes.

More and more each year it is significant and encouraging to note the willingness on the part of the poultrymen and farmers to assume a large part of the entire expense of financing the extension engagements. This enables the Department to do a very much larger amount of work at a comparatively small cost to the College, or, in other words, to do a vastly larger amount of work in the State with the amount of money available for this purpose. The entire cost to the College for traveling expenses during the year was $1787.59, which is $30.39 less than last year notwithstanding the fact that there was an increase in the number of extension engagements.

JULY 1, 1917—JUNE 30, 1918

Poultry extension lectures and demonstrations

In cooperation with	Places	Number of lectures and demonstrations
Poultry associations	23	60
County farm bureaus	289	416
Fair associations	9	49
Demonstration schools	5	23
General	31	46
Total	357	594

Poultry extension educational exhibits

In cooperation with	Places	Number of days
Fair associations	7	31
Poultry associations	8	35
Total	15	66

Miscellaneous

	1916	1917	Difference
Farm visits (88 places)	176	227	+51
Stock selected	10,145	12,507	+2,362
Stock pledged for selection	153,032	378,713	+225,681
Lectures and demonstrations	472	594	+122
Number of places	254	357	+103
Attendance at meetings	19,801	19,140	—661
Traveling expenses	$1,817.98	$1,787.59	—$30.39

General summary

	July 1, 1916–June 30, 1917	July 1, 1917–June 30, 1918
Lectures	281	175
Demonstrations	191	419
Educational exhibits	190 days	119 days
Farm visits	176	227
Attendance	19,801	19,140

Research.— The nature of research projects in operation during the year, and the numbers of fowls involved, were as follows: inheritance of egg production, 815 fowls; inheritance of egg characters, 47; miscellaneous breeding experiments, 47; methods of feeding, 171; influence of electric lighting, 259; feed tests, 259; total, 1598. Because of the serious feed situation, due to the high cost and scarcity of feed and the neccssity of using substitutes, a large proportion of the research projects relate to improvement in feeding methods.

The difficulty in securing an adequate supply of eggs during the fall and winter months has led to the inauguration of investigations of the economic value of artificial illumination to induce egg production. The results to date confirm the practical experience of producers, and justify the belief that illumination is likely to greatly influence the winter production of eggs. The importance of securing high egg yield in order to meet the excessive increase in the cost of production warrants the continuance of the extensive and costly system of pedigree breeding to improve laying qualities. The College now has a large number of high-producing fowls, many of the offspring of which have been made available to the breeders of the State. Among these are fowls that have records of 915 eggs in seven laying years, 1000 eggs in seven years, and 1062 eggs in eight years — which is believed to be the largest record for a long period.

During the year the administration of the new game farm has been assigned to this Department. A tract of land of 176 acres, east of and adjacent to the college farm, has been purchased. An instructor in game farming has been appointed and a trained foreman has been engaged. Progress is being made in stocking and equipping the farm for teaching and research purposes.

Recommendations.— The efficiency of the Department and the appearance of the plant could be greatly increased by the construction of important and comparatively inexpensive buildings to complete the original plan. Those needed are an incubation building and a judging pavilion at the teaching plant, three or more large laying units for demonstration purposes, and a service building on the poultry farm. Funds should be provided for drainage, fencing, plantings, roads, and walks, if the poultry farm is to be handled efficiently and if it is to be maintained in keeping with the other college property.

RURAL ENGINEERING

H. W. Riley, Professor of Rural Engineering

The present acute shortage in agricultural labor and the high feed prices have forced many farmers to the use of the gas tractor. Most farmers realize that because of the sensitiveness of the gas engine they must be well instructed in its operation and care if they are to undertake farming by gas-engine power with any degree of certainty. Accordingly, when the New York State Food Commission, the farm bureaus, the tractor companies, and this Department announced last winter that a series of tractor schools would be given in different towns throughout the State, there was an immediate response. In January, February, and March, twenty schools were held, at which 1176 persons were enrolled. About 75 per cent of these were actively engaged in farming, some making a great sacrifice to attend. The interest was well maintained, the average attendance being about 82 per cent. The average enrollment was 58.8, and from 3 to 10 tractors were available for study, the average for all schools being 5.6.

The two special tractor schools held by the Department of Rural Engineering were each of three weeks duration and were held in the six weeks following the close of the regular winter course. In each the enrollment was approximately the maximum permissible number of 40, and the work consisted of two lectures and two laboratory periods a day in the study and the actual repair and adjustment of both new and used tractors.

The increase of federal funds under the Smith-Hughes Act has made possible the establishment of a course in farm shop work for agricultural teachers, and such a course has been started in charge of L. M. Roehl. The work is progressing in a very satisfactory manner.

In the administration of the power ditching machines which the Food Supply Commission has purchased and placed under the jurisdiction of different farm bureaus in the State, the Commission has turned to the College of Agriculture for technical assistance, and Professor Robb, of this Department, cooperating with the farm bureaus, has been placed in charge of the technical administration of the ditchers. In emergencies various other members of the Department have assisted in surveying in advance of these ditching machines, and have also in some cases been of material aid to the operators in overcoming mechanical difficulties.

In order to keep closely in touch with actual difficulties encountered by farmers in the use of their farm tractors, the Department has instituted in a small way a local tractor service administered by regular members of the departmental staff. A considerable number of calls have been made, much practical assistance has been given, resulting in decidedly increased food production, and many valuable lessons as to the kinds of difficulties which delay farmers have been learned.

LANDSCAPE ART

E. G. Davis, R. W. Curtis, Professors of Landscape Art

Teaching.— The teaching work of the Department of Landsape Art has gradually crystallized into the policy of giving both general and technical instruction in answer to the needs of three classes of students. The first of these classes comprises mainly students of the College of Agriculture who desire a better understanding of the elementary principles of landscape architecture; such a brief introduction to the principles of this profession will afford the coming generation of country folk a more intelligent point of view in the problems of rural community improvement. The second class comprises students pursuing other technical courses in the University which are somewhat allied to landscape art, such as forestry, architecture, and civil and municipal engineering; such students elect from both elementary and technical or advanced courses. The third class comprises professional students of landscape architecture.

In last year's report it was stated that in the preceding nine years the enrollment (without duplication of students electing more than one course in any year) had increased from 12 to 450. The greater part of this increase was due to the increased enrollment of students of the College of Agriculture in the elementary courses. The number of professional students, including graduates, has for several years been limited to 35. Drafting-room space, and also the limited teaching staff of the department, do not permit a larger registration. Courses of study now offered represent satisfactorily the various subdivisions of the field of landscape architecture, but considerable amplification and perfecting of these remains to be done.

It is of considerable interest to note the important bearing of landscape architecture on war activities. Most of the planning and direction of construction of the cantonments last year and of the industrial settlements this year has been and is under the direction of landscape architects, in the latter case more especially in cooperation with architects and engineers. While the students of landscape architecture, like all others, naturally prefer branches of the service affording active fighting, the need of men trained for planning has led the Government to select such men from the ranks and to assign them to the Cantonment Division at Washington. A large number had already voluntarily entered that Division since the beginning of the war. A number of our students in the various camps have been detailed on minor rearrangement problems, and even on the planting of the grounds about the hospitals and recreational buildings. Many students have gone into engineers' regiments, some into the camouflage units, and others in France into the reconstruction work of laying out temporary and replanning old settlements. Systematic correspondence is being maintained with all students in war service and careful records are kept of their activities.

Extension.—The purpose of the extension work of the Department is to improve country-life conditions in the home, the school, and the village, and to enhance the value of farm property by better arrangement of buildings and grounds and by more attractive plantings of trees, shrubs, and vines. On the request of county agents, school supervisors, village improvement societies, and individuals, visits have been arranged, illustrated lectures given, and data taken from which plans and recommendations have been prepared. Correspondence and later visits have been made to follow up this work of improvement. In addition it is planned to make a limited number of demonstrations of the arrangement, grading, and planting, where the finished result will serve as a model for the whole community.

A new extension instructor has been giving full time to the organization of this phase of the work during the past year. An increasing number of extension letters have been answered and one new piece of work has been begun. This is the making of farm landscape surveys to record the actual conditions of arrangement and adaptation of farm lands, for use in the different farm types throughout the State. The work has been carried on in connection with the Department of Rural Engineering, two representatives, one from each Department, having worked together on a two-days survey once a week during the spring months. This survey will give reliable data on which to make studies and recommendations for future improvements, and is essentially fundamental to a sound extension policy. It is directly in line with the earlier extension program of the Department as outlined in the Annual Report for 1915: "A landscape survey of New York State should be made, with a photographic record of the actual landscape setting, including the farm home, the country roadside, the rural school, the village and town centers, the state institutions, the railroad lines, the barge canal, and all other important features that contribute to the landscape of the State."

RURAL ECONOMY

G. N. Lauman, Professor of Rural Economy

The results of the study of the cooperative efforts in the Chautauqua-Erie Grape Belt, made by the Department of Rural Economy, are now in manuscript and receiving the final touches, such as the information about the 1917 crop.

With each succeeding year the Department's quarters become more and more congested, and the use of its facilities is being seriously abridged by the storage of current material in out-of-the-way places. The Department can no longer accommodate its graduate students, and the congestion is a real detriment to its work.

RURAL EDUCATION

G. A. Works, Professor of Rural Education

Teaching.— Funds made available by the passage of the Smith-Hughes Act, together with those from state sources, have made it possible to make needed additions to the instructional staff in the Department of Rural Education. Assistant Professor Paul J. Kruse, formerly of the University of Washington, has taken charge of the work in educational psychology; Professor William F. Lusk, from the University of Minnesota, has taken charge of the special methods work in agriculture; and Assistant Professor Rolland M. Stewart, of the University of Iowa, was selected for the work in principles of teaching. These additions, together with the establishment of the demonstration school of agriculture at Trumansburg, have made it possible to strengthen the teaching work of the Department very materially. The decline in student registration has made it impossible for the Department to obtain enough men for the positions available in departments of vocational agriculture.

Extension.— The following figures show the distribution of the Cornell Rural School Leaflet for 1917–18:

Persons receiving the leaflets:	
Rural teachers	15,117
City and village teachers	12,124
Training class pupils	721
Training school and normal school pupils	1,406
Pupils in rural schools	155,889
Permanent list	1,106
Junior Home Project workers, approximately	5,000
Total	191,363

Number of copies distributed:

Total rural teachers (one number)	15,117
8,699 teachers who returned lists of pupils (one additional number)	8,699
City and village teachers (one number)	12,124
Training class pupils (two numbers)	1,442
Training school and normal school pupils (two numbers)	2,812
Pupils in rural schools (one number)	155,889
Permanent list (three numbers)	3,318
Junior Home Project workers (one number)	5,000
Total	204,401

There are enrolled at present approximately 24,000 Junior Home Project workers, distributed throughout the various home projects as follows: corn, 560; potato, 1716; home garden, 15,159; canning, 562; food, 1104; poultry, 768; pork, 1213; calf, 487; cow testing, 29; sewing or garment making, 1069; bean, 496; sheep, 178; rabbit, 7.

Investigation.— The Department has cooperated with the local school authorities in Livingston County, and with the State Department of Education, in a rural school survey for that county. Professor Kruse has been in charge of this work for the Department.

HOME ECONOMICS

Martha Van Rensselaer, Flora Rose, Professors of Home Economics

The work of the Department of Home Economics during the past year has been greatly increased owing to the added activities imposed on it by war conditions. In addition to the regular teaching and departmental work, each member of the staff has assumed responsibility for some service connected with the state or the national program for food conservation. The extension work has necessarily been strongly emphasized, this being the readiest way of carrying a knowledge of food conservation from the College to remote parts of the State. In order to insure a more complete unison between federal and state programs, Miss Van Rensselaer went to Washington on March 1, 1918, on a six-months leave of absence, to act as Director of the Home Conservation Division of the United States Food Administration.

Teaching.— No increase has been made in the number of courses in foods and nutrition, but emphasis has been laid on the wise selection, substitution, and utilization of foods with a view of conserving food, money, time, and health. The problem of the cost of living has been restudied on the basis of new conditions. Laboratory practice has been adapted to include the cookery of the substitutes made necessary by the rulings of the Food Administration.

In the clothing division, a considerable part of the work done was for the Red Cross or for Belgian relief. In two of the courses the students contributed practically all the material used. In one course old garments were collected, renovated, and remodeled, for sending to Belgium. A course in vocational work, made possible by the passage of the Smith-Hughes bill and intended for students who desire to become teachers in vocational high schools, was added in the second term. The laboratory is conducted as nearly like a dressmaking shop as is possible with the limited equipment of the Department. The work is done largely for persons outside the class, each student making at least one garment for outside custom. The aim is to acquire skill as far as possible. An extra problem requiring outside time was introduced in the millinery course for the purpose of making soft wool hats for refugees.

The course on women in industry has been adapted to present-day conditions and problems of women engaged in industrial work, stress being laid on conservation of the strength and vitality of women and children in war time. The course in house planning has emphasized conservation as applied to planning the home kitchen in such a way as to conserve the vitality and the time of the worker. The course in design has been adapted to the present situation by emphasizing in house-furnishing the skillful use of old materials or inexpensive new ones, in order to make an attractive interior with meager resources. The study of costume design has focused on sensible everyday garments, and has included becoming combinations of old materials for war-time clothing.

The extension course has had as its aim the special training of seniors to take up food conservation work in the State. Emphasis has been laid on food preservation and on the use of conservation substitutes, through demonstrations and public speaking. Lectures on publicity and the preparation of material for the press have been given, to open up other avenues for reaching the public in county-agent work.

Cafeteria.— To serve only such food as was consistent with the rulings of the Food Administration has required much experimental work in large-quantity cooking. By observing wheatless and meatless days, and by reducing the amount of sugar and fat used, the cafeteria has been able to save each month about 1800 pounds of wheat flour, 1000 pounds of meat, 900 pounds of sugar, and 500 pounds of fat.

Extension.— The extension staff has been used in organizing and carrying on the campaign for food conservation. The number of extension meetings held was 251, and about 40,853 persons were reached. These meetings have included demonstrations; meetings with study clubs, Red Cross, women's clubs, teachers' associations, granges; community singing; community center work; county organization; campaign meetings. Several members of the extension staff have given assistance in the projects of farm bureaus and the New York State Food Commission.

Five extension schools in foods have been held in counties where there was no local agent, to create if possible a desire on the part of the county to finance an agent. The extension school has been urged less than usual because of the immediate pressure of other extension activities of wider range.

Two instructors, working in cooperation with the Department of Rural Education, have carried out projects in foods and clothing during the year. Twenty-four new circulars for carrying the subject matter have been written, and certain old ones have been revised to fit the present war work. In the clothing project the children were given regents credit for making garments to be distributed by the Red Cross and the Franco-American Committee for the Protection of the Children of the Frontier. The food work has been adapted to follow conservation regulations. From September 15, 1917, to June 30, 1918, 221 field meetings were held, with an attendance of 35,980. Ten fairs were visited and the project work at the fairs was judged and prizes were awarded. The total registration in Junior Home Projects in foods and clothing on June 30, 1918, was 3920. The organization and follow-up phases of the junior extension work have been transferred to the Department of Home Economics from the Department of Rural Education. This has necessitated a larger office and more office help.

Reading Course for the Farm Home.— Since July 1, 1917, the regular publication of lessons in the Cornell Reading Course for the Farm Home has been somewhat interrupted by the issuing of emergency publications which could be quickly printed in the form of mailing cards published in cooperation with the New York State Food Supply Commission, and war-time conservation bulletins published in cooperation with the New York State Food Commission and the Federal Food Board. Besides the reading-course lessons and the mailing cards, which are listed elsewhere, the following State Food Commission bulletins have been issued by the Department:

Wheat-saving breads
Milk as meat and drink
Potatoes for patriotism
For the meatless day
Sugarless sweets
How to use wheat substitutes
Seven commandments for buying the daily food
Without wheat

Revision of the mailing list was begun in October, 1917, by sending out franked postal cards with a return card attached. This work is now practically completed. The old list, including club members, contained 82,605 names; the new list at present contains 63,461 names. In addition to this number of readers regularly receiving publications, 25,922 individual requests for lessons have been filled, 3179 of which were from outside the State. During the present emergency, more out-of-State persons have been enrolled than is ordinarily the policy; since July 1, 1680 non-residents have been added to the list. Besides the requests for reading-course publications, the Department received and filled during February and March 600 requests for Food Commission bulletins. The largest number of individual requests for Department publications was 4995, in October.

Cornell study clubs.— Twenty-one new study clubs have been added to the list during the year, making a total of 258 with an average membership of 25. The clubs have been of particular service in the food conservation work in their communities, because they were a ready-made nucleus for community interest with which the county food conservation agents might work. Twenty-seven programs on food conservation, with references for study, have been prepared by the Department and sent to the clubs as guides for their meetings. These programs have included such subjects as canning, drying, and salting of various fruits and vegetables in season; the making of jellies; the continuous and intermittent methods of canning; bacteria as related to canning; the construction and use of fireless cookers; the wider utilization of fruit juices; planning meals, including meals for harvest hands; the making of meat-substitute dishes; the use of milk; the conservation of fats; the conservation of wheat and the use of wheat substitutes; the food needs of the family; the spring garden; and the preservation of eggs and butter.

Special food conservation work.— During the year the Department carried out, in cooperation with the New York State Food Supply Commission and its successor, the New York State Food Commission, a state program on food conservation. From July 1 to November 1, 1917, thirty-six counties and seven cities, with a food conservation agent in each, were organized by the Department, in addition to the five counties that had already been permanently organized. In November the organization was taken over by the Farm Bureau and the Food Commission, and the program was left with this Department.

The Department has planned, outlined, and directed through the county home demonstration agents, a state-wide campaign for the increased use of milk, in an attempt to counteract the diminished consumption due to the rise in price. A campaign for the use of other dairy products has also been developed. A campaign for the increased use of potatoes was undertaken for the purpose of utilizing the surplus and saving wheat.

During the summer of 1917 three emergency schools of from six to ten days each were held at the College, for the purpose of giving to candidates for positions as county food conservation agents some understanding of the problems and organization of extension work, as well as recent information in subject matter. These schools lasted through the entire day and the evening, and were conducted by staff members who contributed the time from their rest, recreation, or study periods.

The time of various members of the foods staff has been required for experimental cookery as related to food conservation. A special study of wheat substitutes for breads, cakes, cookies, pastry, and other dishes has been made. Uses for dairy products have been developed. The use of sugar substitutes, such as sirups, molasses, and honey, has been studied. Experiments have been made in canning vegetables with acid, preserving vegetables with salt and with salt and acid, canning fruits and vegetables, and drying fruits and vegetables, and with pastes made from fruits and vegetables. To encourage the drying of fruits and vegetables, experimental work has been done on the cooking of dried products including the time of soaking. Special work was done on the preservation of fourteen varieties of New York peaches and twenty-four varieties of New York apples.

During the preserving season the foods staff contributed daily two or three recipes for canning, drying, or salting foods, which were sent to the newspapers of the State through the publicity bureau maintained by the Department and the New York State Food Supply Commission. Since December it has contributed conservation menus for each day of the week, which have likewise been sent to the newspapers of the State.

The number of questions on foods that come in daily from all parts of the State has increased greatly since the emergency began. These have often required investigation on the part of the staff. As a result, a food question box has been conducted in the State newspapers through the publicity bureau for the benefit of readers interested in food problems.

As part of the work on conservation of fats, an exhibit showing ways of utilizing excess fat from meats was prepared and sent to the food conservation agents.

During the summer of 1917 Dr. Harold L. Lang, a bacteriologist, and Mr. Newbill, a canner, both from the United States Department of Agriculture, together with Miss Elizabeth Genung, of Simmons College, carried on canning experiments in cooperation with the College. They were assisted by Misses Bertha Yerke and Alice C. Van Scoy, of this

Department. The purpose of the experiments was to test the merits of the continuous and intermittent methods of canning. About forty cans of vegetables were prepared. Miss Genung opened some of the cans in September, and the cultures were sent to Dr. Lang; the final test was made in March, 1918, when twenty-two jars were opened by Dr. Lang and Miss Genung. The results showed that the bacteriological contents were about the same in both methods. As to flavor, texture, and general characteristics, there was not a perfect sample. This investigation was merely a preliminary step in an attempt to throw light on this many-sided problem.

Community kitchens which have been operated throughout the State since war was declared were investigated by two members of the staff, for the purpose of gathering data which would help in the organization of new kitchens for preserving foods as well as those serving as cooked-food centers. Housing, equipment, labor and schedules, supplies, methods of financing, and disposal of products, were among the phases studied. In connection with this work, a community kitchen was equipped in the basement of the Home Economics Building for the canning of fruits and vegetables during the summer of 1918, by women living near the campus.

For four weeks during July and August, 1917, two demonstration cars were run over the New York Central lines in cooperation with the New York Central Railroad and the New York State Food Supply Commission. Two members of the staff demonstrated the preservation of foods in season, exhibited equipment, and distributed printed matter. Twenty towns were visited, and in spite of the hot weather the average daily attendance was between 150 and 200.

A demonstration train organized to help housewives in adapting their home programs to the war emergency began its schedule on May 9, on the New York Central lines along both sides of the Hudson River. This work was carried on through the cooperation of the College of Agriculture, the Federal Food Board, and the New York Central Railroad. Demonstrations on wheatless breads and other uses of wheat substitutes, and on milk dishes, meat savers, and sugar savers, were given. Exhibits of wheatless breads, canned and dried foods, eggs preserved in water glass, an iceless refrigerator, a homemade fireless cooker, and equipment for canning and drying, were displayed. State and federal printed matter was distributed. During May and June thirty-four demonstrations were given, with a total attendance of about 3420.

At the National Milk and Dairy Farm Exposition, which was held in May, 1918, at the Grand Central Palace in New York City, three members of the Department directed the section on the uses of milk as a food, planning the general color scheme, furnishing, and signs for the exhibit. Sample milk dishes were served, to encourage consumers to use milk more freely. Three demonstrations a day in each of four booths were given to teach the making of milk dishes. Squads of school children were served with model suppers of dairy products during one hour each day. The work was done in cooperation with the State Food Commission.

At the National Food Show held at the Grand Central Palace in New York City from June 14 to June 22, 1918, a member of the staff gave demonstrations every afternoon and evening on wheatless breads, pastry cakes, and the like. Another member of the staff directed the exhibit of dairy products. This work was done in cooperation with the State Food Commission. It was estimated that 700 persons were reached daily.

The bake shop of the cafeteria has given the results of much of its experimental work to the United States Food Administration, and it has been used as a laboratory to try out recipes for the Food Administration. Recipes for both large and small quantities have been worked out. The head baker has demonstrated the making of war breads in Syracuse three times at the State Fair where over 3000 small loaves of war bread were baked and distributed, at a hotel where approximately 2500 persons were reached, and again before about 40 institution managers. In Troy he baked and exhibited bread for three days, reaching about 3000 persons. He has demonstrated the making of war breads for bakers in Washington at the request of the Food Administration. Over 5000 small loaves of war bread have been sent out to the home demonstration agents for demonstration purposes.

A course of twelve lessons was prepared for nurses of New York State to place before them the war food situation, the measures advised and adopted by the United States Food Administration, and some of the most recent printed matter on food and dietetics. The course was prepared originally for the nurses of the New York State Organization for Public Health Nursing, numbering about 250. Since the lessons were first sent out, however, the list has grown to 1316. The lessons were followed by a questionnaire to be returned to the Department.

Cooperating with the New York State Food Supply Commission, special publicity work was inaugurated the middle of July, 1917, to place before the people of the State, through the press and through every other possible channel of publicity, facts and subject matter bearing upon the emergency food situation. Part of the work of this bureau was a course of lectures in journalism to students of the extension class of the summer school. A similar course of six lectures was given to the extension class during the first term of the regular course. With the discontinuance of the State Food Supply Commission the bureau of publicity was taken over as a part of the extension work of the Department, working in close cooperation with the later New York State Food Commission.

This bureau has issued newspaper articles bearing upon various phases of the emergency food problems. It has issued also magazine articles and special Sunday feature articles, urging or explaining some phase of conservation. It has directed the regular publicity of the county and city agents, helping with special campaigns in such ways as planning exhibits and preparing press material and slogans for motion picture theatres. In cooperation with the conservation bureau of the New York State Food Commission, the publicity bureau has taken over the work of issuing to the press of New York State outside of New York City the news material sent from the United States Food Administration for redistribution. The material has been issued in weekly or biweekly bulletins to home demonstration agents, federal food deputies, and county agents.

The keynote of demonstrations, lectures, and exhibits during Farmers' Week was conservation. Special attention was given to substitutes for wheat, sugar, and meat, to the remodeling of old clothing, and to the fireless cooker, and a conservation kitchen was illustrated by a full-sized model with all necessary equipment. Outside speakers discussed health conservation, the welfare of children, and the food supply in relation to world politics.

The Department arranged an extensive exhibit for the New York State Food Supply Commission at the State Fair at Syracuse.

Recommendations.— It is recommended that continued provision be made for increasing the number of extension workers in the Department. It is believed that a staff of from thirty to forty trained women should be constantly in the field representing the various subject-matter divisions.

METEOROLOGY

Wilford M. Wilson, Professor of Meteorology

Teaching.— In view of the increased interest, throughout the country, in meteorology in its relations to agriculture, the Department of Meteorology plans to offer several new courses. Graduate work toward advanced degrees, acceptable to the Graduate School, has been given in the Department this year for the first time.

Investigation.— The Department is now working on the climate of New York State and its relation to the agricultural industries of the State. Also, work is being done on evaporation, and on the effect of low temperatures on fruit buds. It is hoped that when this work is completed definite information will be available regarding the various climates in different parts of the State and the climatic limitations of some of the staple crops, and also detailed information on evaporation and its influence on vegetation. The results of these investigations should be of value to the farmers of the State.

EXTENSION

M. C. Burritt, Professor in Extension Service and Vice Director of Extension

Administrative changes.— The administration of the extension work of the College was reorganized on July 1, 1917. The former Department of Extension Teaching, the Office of Publications, the Office of the State Leader of Farm Bureaus, and the newly created Office of the State Leader of Home Demonstration Agents, were combined to form the Extension Department under the leadership of M. C. Burritt, who was made Vice Director of Extension. This organization is administrative and functions as a branch of the Dean's office. Together with the extension specialists of the subject-matter departments, it constitutes the Extension Service of the College. The Extension Department now has the following four main divisions:

1. General administration, including (a) finances, (b) extension schools and meetings, (c) reading courses, and (d) miscellaneous activities. The work of the specialists in large measure clears through this division.
2. Office of publication, including the editing of experiment station and extension publications and the general dissemination of information.
3. Office of county agricultural agent leader.
4. Office of home demonstration agent leader.

Changes in personnel.— Dean Mann and Professor Burritt continued to serve as commissioners of the New York State Food Supply Commission until October 18, 1917. Several other members of the staff also devoted several months to the work of the Commission. On November 1 H. E. Babcock was given leave of absence to assist President Schurman in the work of the new State Food Commission. E. R. Eastman was appointed Assistant County Agent Leader on August 1, 1917, and on March 1, 1918, was given leave of absence for organization work with the Dairymen's League. On July 1, 1917, F. E. Robertson and L. A. Toan were appointed part-time assistants in the Central Farm Bureau Office, and both were regularly appointed Assistant County Agent Leaders beginning January 1, 1918. E. P. Lott, instructor, resigned on December 1, 1917. G. R. Phipps, instructor, resigned on January 1, 1918, to accept a commission as captain in the United States Army, and C. W. Whitney, instructor, resigned on June 1 to enter military service. R. W. Pease was appointed assistant in the Central Farm Bureau Office on November 1, 1917. G. Hammond was appointed assistant in the same office on February 1, 1918. In the Office of Publication, Ralph W. Green resigned on January 1, and M. V. Atwood was appointed on February 1 to fill the vacancy.

Office of Administration

Extension schools.— In view of the general shortage of farm labor, making it difficult for farmers to leave their routine work, it was thought advisable to reduce the number of five-day schools in favor of one-day community meetings. A summarized statement of the schools held follows:

Number of schools held	29
Counties reached	20
Total enrollment	993
Average enrollment	34.2
Highest enrollment (at Avon)	115
Lowest enrollment (at Freehold)	15
Highest percentage of attendance (at Phelps)	74
Average attendance per session	17.4
Average number of instructors per school	2.9
Length of school season (weeks)	12

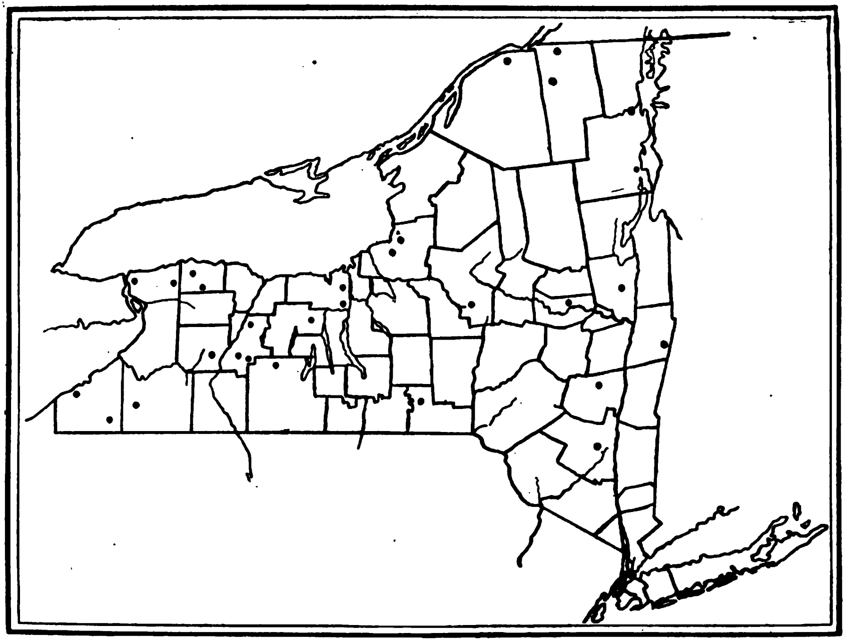
Instruction was given as follows:	Number of days
Agricultural chemistry	4
Animal husbandry	92½
Entomology	2
Farm crops	19
Farm mechanics	11
Farm management	21½
Pomology	18½
Plant breeding	11
Plant diseases	28
Poultry	15½
Soils	68½
Vegetable gardening	11½

The accompanying map (page lxx) shows the location of schools during the season 1917–18.

In addition to the foregoing, attention should be called to the tractor schools conducted by cooperation between the College and the New York State Food Commission, a record of which is included with the report of the Department of Rural Engineering.

With the larger growth of the farm bureau organization and the greater number of informal community meetings, opportunity is at hand for the further anticipated development of the extension schools to make them more advanced, so that they may continue to appeal primarily to the more forward-looking and intelligent farmers. To this end instruction in a given school will hereafter generally be confined to one subject instead of from two to three, presenting such relatively restricted phases of agricultural science as drainage, management of special crops such as fruits, beans, and potatoes, and the like. Some of these schools will be presented in courses of less than five days.

The schools have always appealed to the younger men — farm boys who are unable to leave work on the farm for a full course at the College. Many of these have been called for military service. For the duration of the war, therefore, it is to be expected that the extension-school work will need to be more or less restricted, both in the number of schools held and possibly in the attendance per school also. The quality of the work, however, will be raised rather than lowered.



DISTRIBUTION OF FARM DEMONSTRATION SCHOOLS, 1917-18

Community meetings.— During the year extension specialists representing eighteen subject-matter departments spent 2789 days in the field. This does not include time spent in traveling. Meetings held are classified as follows: 799 demonstrations, at which 28,028 persons attended; 999 lectures, attended by 93,504 persons; 1409 inspection trips and farm visits; 44 conferences, with 2491 persons in attendance. In addition, 248 days were spent at exhibits and conventions. A total of 125,432 persons were reached by the extension specialists during the year, and every county received extension service.

Fairs and exhibits.— The College of Agriculture was called upon to send exhibits to the State Fair, to the Rochester Industrial Exposition, to six county fairs, to the meeting of the New York State Fruit Growers' Association, to the meeting of the Western New York Horticultural Society, and to the National Milk and Dairy Farm Exposition. Because the building usually available for the state institutions at the State Fair was occupied by federal troops, it was necessary to depart from the usual type of exhibits, and the College cooperated with the New York State Food Supply Commission and arranged its exhibits under the direction of the latter. Departmental exhibits as such were eliminated, and a few main subjects of greatest importance in the work of food production and conservation were emphasized. Twelve departments supplied material for these exhibits. This grouping of departments under main subjects, such as milk production, potato production, and drainage, seemed to have many advantages and should be considered in the preparation of future exhibits. Exhibits sent to the Rochester Industrial Exposition related to fruit growing, as did the exhibits to the fruit meetings. The call from county fair organizations for exhibits was not urgent, as heretofore, probably due to the unsettled conditions caused by the war.

The part taken by the College in the National Milk and Dairy Farm Exposition was in accordance with an act of the Legislature appropriating $30,000 to be spent by the Department of Farms and Markets in cooperation with the State College of Agriculture for the making of an exhibit at this exposition. The exposition was held during the week of May 20 at the Grand Central Palace in New York City. In this enterprise the College, through its Departments of Animal Husbandry, Dairy Industry, Farm Crops, Farm Management, and Home Economics, cooperated with the State Department of Farms and Markets in staging three distinct units: (1) a graphic representation, by means of charts, pictures, animals, feeds, model structures, and utensils, of the factors involved in the production of milk, including the raising of the calf, the maintenance of the cow, and the milk produced; (2) the actual manufacture on the spot of butter, ice cream, and several kinds of cheese, and demonstrations of milk testing and examinations for purity; and (3) demonstrations on the food value of milk, and the making of milk and its products into many articles of diet, which were sold to visitors at the exposition at a nominal charge. The attendance for the six days of the exposition was reported as 72,199.

Farmers' Week.—The eleventh annual Farmers' Week was held at the College February 11 to 16. Although the registration was about five hundred less than last year, the interest was excellent and this Farmers' Week was one of the best ever held at the College. The program was arranged to give prominence to the subjects pertaining to food production and conservation. Several lectures on subjects relating directly to the war were given by persons prominent in national and state affairs. Among the new features on the program this year were two forums, one on the township system of schools and the other on the economics of milk production. Both these forums were largely attended and developed free and spirited discussion. In addition to the regular staff of the College of Agriculture, sixty-three outside speakers took some part in the program, which may be summarized as follows:

Lectures given	293
Demonstrations	17
Round-table periods	16
Conventions and conferences	12
Practice periods	32
Exhibits	20
Entertainments and banquets, including motion pictures	12
Contests, including students' judging and speaking	12
Registration for week	3,095

Demonstration cars.— A potato demonstration car was operated over the Lehigh Valley Railroad from September 17 to October 5, 1917. The car was fitted up with exhibits relating to grading and storage, seed selection, and potato diseases and treatment of seed. The demonstrations, which were given at the car and in the communities where the car stopped, related particularly to proper grading and storage, this subject being especially emphasized because of the Federal Government's suggestions on handling the potato crop. The car was operated through the counties of Tioga, Tompkins, Cortland, Cayuga, Ontario, Monroe, and Livingston. Twenty-eight stops were made and the attendance was about 400.

Cornell reading course for the farm.— The reorganization of the administration of extension work has enabled the Reading Course for the Farm to establish a closer relationship with the farm bureaus of the State. A program of cooperation was approved by the Annual Farm Bureau Conference in the fall of 1917, and has been followed during the year with good results. The plan involved the preparation of classified sets of extension publications and of publication charts, and the distribution of lessons through the farm bureau offices. Thirty-eight county agents have received a set of 111 extension publications, classified by subjects and mounted in seven loose-leaf covers. No charge was made for the publications themselves, but the farm bureaus reimbursed the College for the purchase price of the materials used. It is purposed to keep the classified sets of publications up to date. The same service has been provided also for local granges, schools, and agricultural organizations, and a number of classified sets have been distributed to these.

The classified sets of extension publications have given county agents a better knowledge of the available bulletins, with the result that a number of farm bureaus have requested a supply. One farm bureau alone has already asked for 3787 bulletins. In order to call attention to the extension publications, folding charts displaying their covers have been sent at cost of material. Ninety-six charts have been distributed to 29 farm bureaus on request.

Cooperation with the farmers' institutes and with the New York State Grange has been further developed. Reading-course lessons, selected according to the subjects to be discussed, have been sent to each farmers' institute for distribution. In this way 53,000 lessons have been distributed. Special publication charts have been provided for farmers' institute conductors as well as for extension school instructors. The Master of the State Grange has taken steps to encourage the use of reading-course lessons by subordinate granges.

The growth of the Reading Course for the Farm has been greater than in any previous year. Eleven farm bureaus sent membership lists to be added to the reading-course mailing list. Fifteen hundred persons registered in the course during Farmers' Week. At the close of the year the mailing list contains 31,000 names. The number of lessons sent out in answer to requests received by mail exceeded 90,000, which is the largest number for any year. At the beginning of the year the mailing list was revised so as to omit the names of persons who had not returned discussion papers for three years and to retain those who had. Sixty-two per cent of the persons on the 1913–14 list had returned discussion papers, thereby registering for a course of reading. The reading course therefore interests practically two-thirds of its mailing list in a course of reading on one or more subjects.

During the year 123 readers have been actively engaged in the work offered in the advanced reading courses in farm crops, fruit growing, and vegetable gardening. The office has received 429 lesson papers on assigned reading, and 38 reports on practical exercises. These lesson papers and reports were corrected and graded by the departments concerned, and returned to the readers with comments and suggestions. The increasing number of local organizations has interfered in recent years with study club work. Six new Cornell study clubs have been organized during the year, and thirteen clubs organized in previous years have been active. Ten lectures were arranged at study clubs.

Office of Publication

The Office of Publication is charged with the duty of publishing the bulletins of the College and the Experiment Station, including their editorial revision and their distribution after they are printed. It also maintains an information service, by means of which the results of investigations are made known to the people of the State through the agricultural and rural press.

The regular publications issued by the College and the Station cover a useful but somewhat limited field. To place even the popular ones in all the farm homes of the State, even if it could be done, would entail an immense expense. Yet the College feels that it should do everything possible to help all farmers apply what the scientists know and what the best farmers practice. With this object in view, the regular publications of the College have been made easier to understand and to apply. The scientific bulletin for the scientist is wholly differentiated from the popular one for the general reader. The publications of the latter group have been made more attractive, brief, simple, and clear.

The agricultural and home economics facts issued during the past year through the cooperation of the press of the State comprised 450 different items, with an aggregate circulation, as shown by press clippings, of 42,959,410, or about 8,000,000 more than the circulation in the year ending June 30, 1917, which was 34,331,422. In connection with agricultural war work these items had to do mainly with food growing and food saving, with special campaigns for increased production of staples and of home garden products and for increased use of dairy products, potatoes, and perishable foods.

The publications issued by the College during the year ending June 30, 1918, are as follows:

	Number of pages in printed bulletin	Number of copies printed
MEMOIRS:		
12 Lysimeter experiments. Records for tanks 1 to 12 during the years 1910 to 1914 inclusive (Department of Soil Technology)	116	3,500
EXPERIMENT STATION BULLETINS:		
392 Heredity studies in the morning-glory (Ipomoea purpurea [L.] Roth) (Department of Plant Breeding)	40	3,000
393 Factors influencing the abscission of flowers and partially developed fruits of the apple (Pyrus malus L.) (Department of Pomology)	76	4,000
394 The decomposition of sweet clover (Melilotus alba Desr.) as a green manure under greenhouse conditions (Department of Agricultural Chemistry)	36	3,000
395 The anthracnose disease of the raspberry and related plants (Department of Plant Pathology)	32	2,000
396 An investigation of the scarring of fruit caused by apple redbugs (Department of Entomology)	24	5,000
397 The refinement of feeding experiments for milk production by the application of statistical methods (Department of Animal Husbandry)	44	2,000
Total	252	19,000

	Number of pages in printed bulletin	Number of copies printed
READING-COURSE LESSONS FOR THE FARM:		
126 Swine production in New York (Department of Animal Husbandry)	36	40,000
127 Farm manure: its production, conservation, and use (Department of Soil Technology)	36	40,000
128 Autumn in the flower garden (Department of Floriculture)	36	40,000
129 Improving the corn crop by selection and breeding (Department of Plant Breeding)	20	40,000
130 Rearing chickens: brooder house construction (Department of Poultry Husbandry)	32	40,000
131 Contagious abortion in cattle (College of Veterinary Medicine)	24	40,000
132 Drying fruits and vegetables in New York State (Department of Vegetable Gardening)	28	90,000
133 Preparation of market eggs on the farm (Department of Poultry Husbandry)	40	40,000
134 Starting a flock of sheep (Department of Animal Husbandry)	20	40,000
Total	272	410,000
READING-COURSE LESSONS FOR THE FARM HOME:		
114 Principles of jelly making (Department of Home Economics)	16	50,000
115 Cornmeal once a day (Department of Home Economics)	4	200,000
116 Make every crumb count (Department of Home Economics)	4	200,000
117 Cereals in the diet (Department of Home Economics)	28	35,000
118 When potatoes are plentiful (Department of Home Economics)	16	35,000
119 Preserving vegetables with salt (Departments of Vegetable Gardening and Home Economics)	20	100,000
Total	88	620,000
EXTENSION BULLETINS:		
20 Grass and clover insects (Department of Entomology)	20	50,000
21 How to select laying hens (Department of Poultry Husbandry)	16	40,000
22 Construction and management of root storage cellars (Department of Rural Engineering)	20	40,000
23 Suggestions to purchasers of farm lands in New York (Department of Soil Technology)	24	10,000
24 Soil survey of Schoharie County (Department of Soil Technology)	36	3,000
25 What is meant by "quality" in milk (Department of Dairy Industry)	20	20,000
26 Seed testing (Department of Farm Crops)	4	45,000
27 Apple and thorn skeletonizer (Department of Entomology)	8	5,000
28 Wholesale prices and receipts of apples in Boston for thirty-six years (Department of Pomology)	12	15,000
29 Soil survey of Cortland County (Department of Soil Technology)	28	3,000
Total	188	231,000

	Number of pages in printed bulletin	Number of copies printed
RURAL SCHOOL LEAFLETS:		
September, 1917 (Department of Rural Education)	322	35,000
November, 1917 (Department of Rural Education)	50	25,000
March, 1918 (Department of Rural Education)	54	200,000
Supplement	2	12,000
Total	428	272,000
EXTENSION CIRCULARS:		
Community demonstration schools in agriculture and home economics (Department of Extension Teaching)	4	5,000
MISCELLANEOUS:		
Information for students	36	1,000
ANNUAL REPORT FOR 1917 (in three volumes)	3,226	2,000
ANNOUNCEMENTS:		
Announcement of instruction in wild life conservation and game breeding	12	3,000
Announcement of summer term, 1918	28	2,500
Announcement of courses, 1918–19	82	10,000
Announcement of winter courses, 1918–19	38	6,000
Total	160	21,500
MAILING CARDS:		
29 Ways of preserving beans and peas	2	100,000
30 How to make an iceless refrigerator	2	150,000
31 Suggestions to vegetable growers on marketing	2	25,000
32 Ways of preserving tomatoes	2	150,000
33 Fruit juices	2	150,000
34 Save the fats — Part I	2	150,000
35 Save the fats — Part II	2	150,000
36 Rejuvenation of old worn meadows and plowable run-out pastures	2	25,000
37 Ways of preserving peaches	2	200,000
38 Making kraut for home use or market	2	50,000
39 Fall spraying for peach leaf curl	2	15,000
40 A dozen kinds of bread	2	150,000
Total	24	1,315,000

SUMMARY

	Total number	Total pages	Copies
Memoirs	1	116	3,500
Experiment station bulletins	6	252	19,000
Reading-course lessons for the farm	9	272	410,000
Reading-course lessons for the farm home	6	88	620,000
Extension bulletins	10	188	231,000
Rural school leaflets	3	428	272,000
Extension circulars	1	4	5,000
Miscellaneous	1	36	1,000
Annual report	1	3,226	2,000
Announcements	4	160	21,500
Mailing cards	12	24	1,315,000
Total	54	4,794	2,900,000

Office of the County Agent Leader

The hearty response of New York farmers to the call for increased production brought upon the farm bureau organization new obligations and a vast amount of detail work. Written requests for information more than doubled, and the number of office calls increased by more than two hundred per cent.

Not only have the farm bureaus increased in strength in the organized counties, but the call from the counties without farm bureaus has been so persistent and earnest that thirteen new bureaus have been organized during the year. The State now has 55 county farm bureau associations, all of them in active operation. Over 45,500 New York State farmers are now farm bureau members, and the average membership per county is 827. The thirteen counties organized during the year, together with their membership on June 30, 1918, were as follows: Columbia, 758; Fulton, 245; Genesee, 1016; Greene, 376; Lewis, 256; Livingston, 938; Rockland, 230; Schenectady, 283; Schuyler, 520; Seneca, 627; Steuben, 976; Washington, 517; Yates, 624.

The volume of work has necessitated the employment of assistants in forty-two counties. The nature of the activities has shifted somewhat in order to meet war conditions. There has been a falling off in the field demonstrations, with a remarkable increase in the number of office calls and work of an organization character. Farmers are more and more coming to see the advantages in grouping their ideas and working in union for the solution of common problems. The various lines of work covered by the county agents and their assistants, with the volume of each, are given in the following table:

STATISTICAL REPORT OF OFFICE AND FIELD WORK OF AGENTS AND ASSISTANTS

	Days in field	Days in office	Calls on agent at headquarters	Letters written	Farm visits made	Demonstrations visited	Meetings held at demonstrations		All other meetings	
							Number	Attendance	Number	Attendance
Total, 55 counties......	9,892	10,597	84,584	124,619	28,964	5,727	1,045	15,306	5,400	244,137
Average per county, 55 counties*...........	180	193	1,538	2,266	527	104	19	278	98	4,439

* When considering these averages it should be noted that only 42 farm bureau associations were in operation during the entire year.

The volume of work done per county has on the whole increased more than one hundred per cent over the pre-war period. County agents, executives, and community committees are making an effort to maintain and increase production, in spite of the added handicaps of scarcity of labor and uncertainty of prices.

The plan of organization has remained essentially the same as last year. Much attention has been given to the organization of community committees, the total number of committeemen now being about 7000. These men are considering agricultural problems from the viewpoint of the community and are making community programs at conferences after careful thought and deliberation. They are learning to think in terms of the community and its interests, rather than in terms of their own farms and as individuals.

The number of farmers in each county, the membership in the farm bureaus, the number of communities, and the number of committeemen on July 1, 1917, as compared with that on June 30, 1918, are shown in the accompanying table. It is significant to note the increase in the number and percentage of farmers who are members of the various farm bureau associations.

An increase in financial support has made possible the added volume of work here noted. During the fiscal year from July 1, 1917, to June 30, 1918, war emergency funds to the amount of $41,556 were made available by the federal emergency agricultural appropriation bill. These funds were used in paying part salaries of regular agents, making it possible to give the new counties the equivalent of regular state and federal funds which had not been provided. Also, all salaries of assistants to a maximum of $100 a month were paid from these funds. During the year $101,723.31 was appropriated by the boards of supervisors in the counties. During the coming year $134,625 will be received from boards of supervisors, and it is expected that $63,210 will be made available from federal war emergency funds. Aside from the special items mentioned, $119,314.25 was provided from membership funds, regular state and federal funds, contributions, and other sources, making a total amount of $262,593.56 available for carrying on the work of the farm bureaus during the year.

Office of the Home Demonstration Agent Leader

At the beginning of the year, on or about July 1, 1917, there were five counties organized with home demonstration agents. There are now fifty-seven agents in the State, including the five agents in permanently organized counties, thirty-two emergency county agents, and twenty assistants.

On May 15, 1918, all the county agents in the State, together with representatives from their executive committees, met with the state leaders at Ithaca for a week's conference and outlined a scheme for a

MEMBERSHIP BY COUNTIES

County	Number of farmers	Membership in farm bureau				Number of communities in the county	Number of community committeemen	Number of executive committeemen
		July 1, 1917		June 30, 1918				
		Number	Percentage	Number	Percentage			
Albany	3,146	290	9	721	23	38	85	9
Allegany	4,937	332	7	498	10	57	74	9
Broome	4,017	487	12	705	17	50	137	9
Cattaraugus	6,107	1,063	18	1,252	21	95	179	7
Cayuga	4,785	564	12	1,152	24	32	154	7
Chautauqua	7,500	......	......	1,000	13	38	181	7
Chemung	2,193	307	14	609	28	24	93	7
Chenango	4,258	846	20	1,025	24	50	115	9
Clinton	3,608	143	4	253	7	28	71	7
Columbia	2,963	......	......	758	25	18	106	7
Cortland	2,610	417	16	825	32	28	118	7
Delaware	5,044	992	20	1,215	24	83	191	7
Dutchess	3,600	536	15	510	14	30	91	8
Erie	8,178	525	6	1,004	12	49	19	8
Essex	2,274	207	9	213	9	22	104	7
Franklin	3,675	676	18	908	25	48	114	7
Fulton	1,932	......	......	245	13	22	10	7
Genesee	3,250	......	......	1,016	31	23	95	7
Greene	2,654	......	......	376	14	25	57	7
Herkimer	3,092	706	23	1,437	46	50	167	8
Jefferson	5,778	840	14	1,030	18	46	126	8
Lewis	3,343	......	......	256	8	27	25	7
Livingston	3,298	......	......	938	28	17	107	7
Madison	4,042	1,046	26	902	22	36	92	7
Monroe	5,971	729	12	1,430	24	19	119	7
Montgomery	2,189	388	18	587	27	28	130	8
Nassau	1,017	387	38	482	47	13	93	8
Niagara	4,346	887	20	1,335	31	33	112	7
Oneida	6,929	583	8	500	7	83	127	8
Onondaga	5,770	545	9	770	13	45	123	8
Ontario	4,416	......	......	675	15	19	139	6
Orange	3,935	1,110	28	1,812	46	55	128	8
Orleans	2,780	760	27	1,020	37	26	139	7
Oswego	6,319	410	6	640	10	95	86	7
Otsego	5,346	1,480	28	1,872	35	62	203	4
Rensselaer	3,654	473	13	396	11	28	109	13
Rockland	1,133	400	35	230	20	10	40	9
St. Lawrence	8,224	236	3	636	8	37	122	7
Saratoga	3,611	213	6	317	9	25	93	7
Schenectady	1,027	......	......	283	27	20	55	8
Schoharie	3,288	482	15	945	29	50	124	12
Schuyler	1,920	......	......	520	27	25	53	7
Seneca	2,085	......	......	627	30	21	85	6
Steuben	7,363	......	......	976	13	44	162	7
Suffolk	2,491	327	13	576	23	35	157	7
Sullivan	3,851	516	13	416	11	44	111	9
Tioga	2,844	925	32	1,267	44	27	140	7
Tompkins	2,988	614	20	1,063	35	32	170	8
Ulster	5,022	450	9	595	12	70	183	10
Warren	1,865	374	20	377	20	27	102	6
Washington	3,564	......	......	517	14	35	49	7
Wayne	5,237	939	18	1,493	28	36	162	9
Westchester	1,880	226	12	209	11	13	32	9
Wyoming	3,529	540	15	1,143	32	38	177	10
Yates	2,288	......	......	624	27	15	65	7
Totals	213,076	23,971	......	43,181	......	2,046	6,101	423
Percentages	....	......	11	......	20	....	....	....

more permanent organization of women's forces throughout the State. It was decided to call the organization the Home Economics Association for Conservation, basing the organization on a membership plan, the question of membership fee being left to the local committees. To date ten of the emergency counties have reorganized under the new plan, and these are now working in the membership campaign.

The chief lines of effort on the part of the agents have been (1) demonstrations in food preservation, (2) demonstrations in the making of "liberty breads," the use of sugarless recipes, and the use of potatoes, (3) a campaign to increase the use of milk, (4) the organization of county home economics associations for conservation, (5) the establishment of community kitchens as canning centers (one county having nine such kitchens), and (6) the establishment of community sewing rooms.

During the year 2282 demonstrations have been given, with a total attendance of 87,519; 2387 lecture meetings have been held, with a total attendance of 144,994; 2776 home visits have been made by the agents and 7470 callers have been received at the various demonstration offices; 22,467 telephone calls have been answered; 23,896 letters have been written and 42,216 circular letters posted; and 3064 press notices have been prepared.

Recommendations

One of the urgent needs of the Extension Department is for more room and a closer grouping of the offices. Several of the offices are crowded, but this is not so serious a handicap to the work of the Department as is the wide separation of the different offices. If all the offices were closely grouped, it would result not only in the saving of much time by eliminating travel between offices several hundred feet apart, but also in bringing the workers into much closer sympathy and cooperation. The storage rooms and work rooms for the mailing division are neither adequate nor suited to their purpose. These are conditions that cannot be remedied at once, but they should be kept in mind in all future plans for improving the service.

FINANCIAL REPORT OF THE NEW YORK STATE COLLEGE OF AGRICULTURE JULY 1, 1917, TO JUNE 30, 1918

Income from Students, Sales, and Services

Income from students:		
Tuition, Regular	$27,650.00	
Winter courses	665.00	
Summer school	2,213.37	
Student fines	1,180.00	
		$31,708.37
Laboratory fees:		
Dairy Industry	$1,432.70	
Poultry Husbandry	220.00	
Entomology	2,308.31	
Farm Crops	388.00	
Botany	3,970.51	
Floriculture	319.50	
Forestry	81.50	
Landscape Art	162.00	
Plant Breeding	153.95	
Plant Pathology	676.67	
Pomology	505.00	
Vegetable Gardening	200.90	
Farm Management	449.25	
Home Economics	5,589.30	
Rural Education	26.95	
Meteorology	104.00	
Rural Engineering	520.00	
Soil Technology	375.61	
		17,484.15
Total income from students		$49,192.52
Income from sales and services:		
Administration:		
General	$3,572.50	
Dean's Office	1,609.46	
Business Office	158.65	
Publications Office	453.98	
Library	0.12	
Engineer's Office	339.01	
Grounds	228.35	
Fuel	1,404.33	
Locker account	71.00	
Animal Husbandry sales	12,528.38	
Dairy Industry	89,537.55	
Poultry Husbandry	9,972.52	
Entomology	544.33	
Farm Crops	80.56	
Farm Practice	15,721.92	
Botany	1,249.00	

Income from sales and services (continued):		
Floriculture	$1,248.90	
Forestry	701.06	
Landscape Art	96.20	
Plant Breeding	396.67	
Plant Pathology	275.24	
Pomology	1,661.57	
Vegetable Gardening	2,066.81	
Farm Bureau	218.42	
Farm Management	10.60	
Home Economics	58,051.90	
Rural Education	610.95	
Soil Technology	794.03	
Extension Department	4,791.18	
Total		$208,395.19

Expense, All Funds

(Exclusive of transfers between departments, but including transfers from one fund to another)

Salaries for instruction, research, and extension work		$419,662.01
Departmental expenses:		
Animal Husbandry	$40,860.95	
Poultry Husbandry	12,916.81	
Dairy Industry	99,865.85	
Entomology	4,689.09	
Farm Crops	3,045.09	
Farm Practice	28,758.61	
Botany	4,481.59	
Floriculture	3,853.66	
Forestry	2,098.38	
Landscape Art	1,309.11	
Plant Breeding	1,733.95	
Plant Pathology	4,383.21	
Pomology	4,500.59	
Vegetable Gardening	3,463.83	
Farm Management	1,988.65	
Farm Bureau	1,050.28	
Home Economics	62,760.66	
Rural Economy	1,272.62	
Rural Education	4,826.34	
Rural Social Organization	21.75	
Agricultural Chemistry	1,248.11	
Drawing	123.46	
Meteorology	525.30	
Rural Engineering	1,831.56	
Soil Technology	3,654.72	
Extension Department	12,779.73	
Summer school	10,303.73	
Additional instruction	35,400.00	

Departmental expenses (continued):		
Investigation of bean production	$6,526.92	
Purchase and maintenance of game farm	13,893.40	
Smith-Hughes work	7,590.33	
		$381,758.28
Administration and general expense:		
Administrative salaries	$62,638.24	
General administrative expense	9,099.38	
Dean's Office	2,520.65	
Secretary's Office	2,198.61	
Business Office	3,076.80	
Publications Office	8,242.48	
Library	1,446.37	
Engineer's Office	9,484.15	
Grounds	5,808.71	
Fuel, light, power, and water	40,064.50	
Locker account	66.00	
Repairs	13,977.74	
		158,623.63
Total		$960,043.92

Smith-Hughes Fund, 1917–18

Receipts from the New York State Department of Education credited to this fund	$4,900.00
Expenditures to June 30, 1918	7,590.33
Overdraft June 30, 1918	$2,690.33

This overdraft represents an advance by the University for the expenditures from April 1 to June 30, for which reimbursement will be made by the New York State Department of Education.

State Deficiency Appropriation, 1917–18

Appropriation for fuel, light, power, and water	$19,000.00
Expended to June 30, 1918	12,189.23
Balance unexpended June 30, 1918	$6,810.77

This balance is covered by liabilities incurred prior to June 30, 1918.

State Appropriation for the Investigation of Bean Production, 1917

Appropriation	$8,500.00
Expenditures previously reported	888.64
Balance July 1, 1917	$7,611.36
Expenditures from July 1, 1917, to June 30, 1918	6,526.92
Balance unexpended June 30, 1918	$1,084.44

This balance is available until May 2, 1919.

State Appropriation for Game Farm, 1917

Appropriation		$15,000.00
Expended:		
For the farm	$11,150.00	
For general expenses	2,743.40	
		13,893.40
Balance unexpended June 30, 1918		$1,106.60

This balance is covered by liabilities incurred prior to June 30, 1918.

State Deficiency Appropriation, 1916

Appropriation		$55,910.00
Expenditures previously reported		42,564.30
Balance unexpended July 1, 1917		$13,345.70
Expenditures subsequent to July 1, 1917, on liabilities incurred prior to that date:		
Administration:		
General	$585.91	
Dean's Office	83.65	
Secretary's Office	41.50	
Publications Office	242.98	
Business Office	35.45	
Engineer's Office	205.37	
Grounds	1,089.32	
Fuel	2,804.64	
Animal Husbandry	54.02	
Dairy Industry	65.35	
Poultry Husbandry	671.25	
Entomology	61.55	
Farm Crops	1.74	
Farm Practice	1,244.22	
Botany	41.88	
Floriculture	171.50	
Landscape Art	125.80	
Plant Pathology	73.61	
Pomology	125.09	
Vegetable Gardening	198.92	
Farm Management	208.69	
Farm Bureau	3.00	
Home Economics	54.58	
Rural Economy	37.41	
Rural Education	12.35	
Agricultural Chemistry	17.25	
Rural Engineering	86.64	
Soil Technology	291.23	
Extension Department	542.51	
		9,177.41
Balance of appropriation lapsed		$4,168.29

State Maintenance Appropriation, 1916–17

Appropriation		$518,325.66
Expenditures previously reported		497,952.82
Balance unexpended July 1, 1917		$20,372.84
Expenditures subsequent to July 1, 1917, on liabilities incurred prior to that date:		
Administration:		
General	$143.79	
Secretary's Office	127.00	
Business Office	197.83	
Publications Office	16.68	
Engineer's Office	770.55	
Fuel	179.64	
Animal Husbandry	32.68	
Dairy Industry	1,560.95	
Poultry Husbandry	254.10	
Farm Practice	275.72	
Botany	452.15	
Floriculture	18.43	
Forestry	144.29	
Landscape Art	200.20	
Plant Breeding	24.86	
Plant Pathology	68.46	
Pomology	289.32	
Vegetable Gardening	237.22	
Farm Management	33.40	
Farm Bureau	27.65	
Home Economics	538.48	
Rural Economy	68.20	
Rural Education	176.75	
Agricultural Chemistry	102.04	
Drawing	9.83	
Meteorology	147.50	
Rural Engineering	151.79	
Soil Technology	46.42	
Extension Department	525.79	
Repairs	6,882.10	
Salaries	44.44	
		13,748.26
Balance of appropriation lapsed		$6,624.58

State Maintenance Appropriation, 1917–18

Appropriation		$709,651.00
Administration:		
General	$1,005.13	
Dean's Office	845.98	
Secretary's Office	1,692.55	
Business Office	1,778.70	

Administration (continued):		
Publications Office	$4,542.20	
Library	806.70	
Engineer's Office	5,241.90	
Grounds	2,592.83	
Fuel, light, power, and water	24,069.77	
Animal Husbandry	11,869.21	
Poultry Husbandry	3,227.67	
Dairy Industry	4,946.78	
Entomology	1,258.37	
Farm Crops	794.16	
Farm Practice	6,877.84	
Botany	1,816.75	
Floriculture	2,331.55	
Forestry	1,513.28	
Landscape Art	861.24	
Plant Breeding	803.50	
Plant Pathology	2,128.52	
Pomology	2,606.92	
Vegetable Gardening	1,247.43	
Farm Management	1,287.96	
Farm Bureau	858.33	
Home Economics	3,222.03	
Rural Economy	1,167.01	
Rural Education	3,013.72	
Rural Social Organization	21.75	
Agricultural Chemistry	860.71	
Drawing	113.62	
Meteorology	99.03	
Rural Engineering	914.19	
Soil Technology	2,203.55	
Extension Department	7,072.56	
Summer school	7,999.48	
Repairs	7,095.64	
Salaries	482,255.81	
Additional instruction	35,400.00	
		$638,444.37
Balance unexpended June 30, 1918		$71,206.63

Of this balance, about $14,000 is covered by liabilities incurred prior to June 30, 1918. The following items will lapse:

Salaries	$32,698.32
Additional instruction	22,475.00
Contingent	2,000.00
	$57,173.32

Income Fund, 1917-18

	Balance July 1, 1917	First term	Second term	Third term	Summer school	Winter course	Delinquent	Total fees
Administration:								
General	$11.12	$15,427.50	$9,817.50	$990.00		$665.00	*$2,595.00	$29,495.00
Dean's Office	72.99							
Secretary's Office	15.88							
Business Office	18.37							
Information Office	229.18							
Library	119.48							
Engineer's Office	269.75							
Grounds	31.05							
Fuel	179.95							
Salaries	176.42							
Dairy Industry	2,217.33	313.55	558.40		$28.00	523.15	9.60	1,432.70
Poultry Husbandry	113.50					199.00	21.00	220.00
Entomology	842.89	839.25	1,177.50	65.50	38.75		187.31	2,308.31
Farm Crops	866.32	150.00	136.00			90.00	12.00	388.00
Farm Practice	405.85							
Botany	596.37	2,218.60	1,371.10	200.26	105.50		75.05	3,970.51
Floriculture	186.71	66.00	111.50	74.00		39.50	28.50	319.50
Forestry	85.41	29.00	34.50	15.50			2.50	81.50
Landscape Art	83.71	71.50	37.00	19.50			34.00	162.00
Plant Breeding	18.48	87.00	3.00	14.00		3.50	46.45	153.95
Plant Pathology	468.73	327.94	248.59	53.70	6.00	38.94	1.50	676.67
Pomology	428.41	273.00	211.00	2.00		18.00	1.00	505.00
Vegetable Gardening	150.87		116.00			27.00	57.90	200.90
Farm Management	374.03	131.25	184.00			134.00		449.25
Home Economics	1,466.13	2,018.75	2,463.50	561.50		379.50	166.05	5,589.30
Rural Economy	0.02							
Rural Education	152.17	8.00	14.00				4.95	26.95
Rural Problems class	1.58							
Agricultural Chemistry								
Drawing	6.39							
Meteorology	335.87	58.00	35.00				11.00	104.00
Rural Engineering	90.75	148.00	177.00	6.00		82.00	107.00	520.00
Soil Technology	803.91	159.79	174.22	7.10			34.50	375.61
Extension Department	1,837.63							
Summer school tuition					2,213.37			2,213.37
Total	$12,657.25	$22,327.13	$16,869.81	$2,009.06	$2,391.62	$2,199.59	*$3,395.31	$49,192.52

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* Including $1,180 reinstatement fees and student fines.

Income Fund, 1917-18 *(continued)*

	Credits, cash items	Credits, net transfers from other departments	Total credits	Debits, cash items	Debits, net transfers to other departments	Total debits	Balance June 30, 1918
Administration:							
General	$3,181.19	....	$32,687.31	$6,827.05	$17,699.76	$24,526.81	$8,160.50
Dean's Office	1,609.46	....	1,682.45	791.13	891.32	1,682.45	....
Secretary's Office	....	$393.25	409.13	337.56	....	337.56	71.57
Business Office	36.47	862.25	917.09	877.73	....	877.73	39.36
Information Office	242.68	2,682.02	3,153.88	3,064.77	....	3,064.77	89.11
Library	0.12	541.00	660.60	639.67	....	639.67	20.93
Engineer's Office	167.57	2,250.76	2,688.08	1,834.74	....	1,834.74	853.34
Grounds	....	1,825.89	1,856.94	1,791.17	....	1,791.17	65.77
Fuel	1,404.33	....	1,584.28	821.22	763.06	1,584.28	....
Salaries	....	....	176.42	....	176.42	176.42	....
Dairy Industry	24.00	391.80	4,065.83	3,335.17	....	3,335.17	730.66
Poultry Husbandry	263.74	1,238.37	1,835.61	817.90	....	817.90	1,017.71
Entomology	544.33	571.62	4,267.15	3,369.17	....	3,369.17	897.98
Farm Crops	45.27	961.10	2,260.69	1,893.90	....	1,893.90	366.79
Farm Practice	2,126.62	3,324.36	5,856.83	2,175.59	....	2,175.59	3,681.24
Botany	9.20	....	4,576.08	840.32	242.12	1,082.44	3,493.64
Floriculture	....	44.19	550.40	436.45	....	436.45	113.95
Forestry	2.38	....	169.29	76.84	39.59	116.43	52.86
Landscape Art	....	159.74	405.45	86.08	....	86.08	319.37
Plant Breeding	....	201.22	373.65	317.06	....	317.06	56.59
Plant Pathology	275.24	1,756.10	3,176.74	2,112.62	....	2,112.62	1,064.12
Pomology	....	....	933.41	515.89	285.27	801.16	132.25
Vegetable Gardening	....	497.00	848.77	511.12	....	511.12	337.65
Farm Management	10.60	....	833.88	458.60	44.50	503.10	330.78
Home Economics	1,104.79	512.93	8,673.15	7,391.17	....	7,391.17	1,281.98
Rural Economy	....	....	0.02	....	0.02	0.02	....
Rural Education	540.45	918.92	1,638.49	1,623.52	....	1,623.52	14.97
Rural Problems class	....	....	1.58	....	1.58	1.58	....
Agricultural Chemistry	....	477.91	477.91	268.11	....	268.11	209.80
Drawing	....	....	6.39	....	6.39	6.39	....
Meteorology	....	....	439.87	278.77	68.26	347.03	92.84
Rural Engineering	....	210.81	821.56	678.94	....	678.94	142.62
Soil Technology	388.34	517.73	2,085.59	787.90	....	787.90	1,297.69
Extension Department	4,791.18	....	6,628.81	4,638.87	211.56	4,850.43	1,778.38
Summer school tuition	....	90.88	2,304.25	2,304.25	....	2,304.25	....
Total	$16,767.96	$20,429.85	$99,047.58	$51,903.28	$20,429.85	$72,333.13	$26,714.45

Circulating Fund, 1917-18

	Balance July 1, 1917	Credits from sales and other income	Credits, net transfers from other departments	Total credits	Debits, cash items	Debits, net transfers to other departments	Total debits	Balance, June 30, 1918
Administration:								
General	$353.26	$391.31	....	$744.57	$537.50	$177.85	$715.35	$29.22
Dean's Office	99.89	....	$700.00	799.89	799.89	....	799.89	....
Business Office	4.47	122.18	72.92	199.57	187.09	....	187.09	12.48
Publications Office	12.07	211.30	152.48	375.85	375.85	....	375.85	....
Engineer's Office	191.29	171.44	1,322.23	1,684.96	1,431.59	....	1,431.59	253.37
Grounds	*1.13	228.35	247.01	474.23	335.39	....	335.39	138.84
Locker account	58.75	71.00	....	129.75	66.00	....	66.00	63.75
Animal Husbandry	7,761.04	12,528.38	10,639.86	30,929.28	28,905.04	....	28,905.04	2,024.24
Dairy Industry	8,285.42	89,513.55	....	97,798.97	89,957.60	6,674.70	96,632.30	1,166.67
Poultry Husbandry	*150.60	9,708.78	....	9,558.18	7,945.89	1,097.67	9,043.56	514.62
Farm Crops	10.12	35.29	323.69	369.10	355.29	....	355.29	13.81
Farm Practice	2,849.33	13,595.30	2,898.51	19,343.14	18,185.24	....	18,185.24	1,157.90
Botany	429.62	1,239.80	0.92	1,670.34	1,330.49	....	1,330.49	339.85
Floriculture	114.54	1,248.90	....	1,363.44	895.75	42.08	937.83	425.61
Forestry	166.74	698.68	....	865.42	363.97	363.21	727.18	138.24
Landscape Art	46.76	96.20	....	142.96	35.79	92.50	128.29	14.67
Plant Breeding	283.67	396.67	....	680.34	588.53	77.77	666.30	14.04
Pomology	466.96	1,661.57	....	2,128.53	963.37	486.17	1,449.54	678.99
Vegetable Gardening	*75.87	2,066.81	....	1,990.94	1,269.14	638.65	1,907.79	83.15
Farm Bureau	*15.51	218.42	48.08	250.99	161.30	....	161.30	89.69
Home Economics	4,686.41	56,947.11	....	61,633.52	51,554.40	6,833.52	58,387.92	3,245.60
Rural Education	....	70.50	....	70.50	....	....	....	70.50
Soil Technology	163.49	405.69	78.42	647.60	325.62	....	325.62	321.98
Total	$25,740.72	$191,627.23	$16,484.12	$233,852.07	$206,570.73	$16,484.12	$223,054.85	$10,797.22

* Indicates overdraft.

Cornell University Agricultural Experiment Station in Account with the United States Appropriations, 1917–18

Dr.		Hatch Fund	Adams Fund
To balance from appropriations for 1916–17		....	....
Receipts from the Treasurer of the United States, as per appropriations for fiscal year ended June 30, 1918, under acts of Congress approved March 2, 1887 (Hatch Fund), and March 16, 1906 (Adams Fund)		$13,500.00	$13,500.00
Cr.	**Abstract**		
By Salaries	1	$7,017.14	$10,708.15
Labor	2	3,208.80	1,334.96
Publications	3	237.00	....
Postage and stationery	4	166.93	57.01
Freight and express	5	67.92	4.57
Heat, light, water, and power	6	21.60	....
Chemicals and laboratory supplies	7	128.22	501.73
Seeds, plants, and sundry supplies	8	336.85	244.50
Fertilizers	9	62.65	143.75
Feeding stuffs	10	....	....
Library	11	19.07	....
Tools, machinery, and appliances	12	669.33	228.60
Furniture and fixtures	13	13.49	....
Scientific apparatus and specimens	14	29.25	210.61
Live stock	15	....	....
Traveling expenses	16	915.04	7.02
Contingent expenses	17	....	....
Buildings and land	18	606.71	59.10
Total		$13,500.00	$13,500.00

Expenditures of Smith-Lever Funds by Projects, 1917–18

Projects	Smith-Lever Funds		
	Total	Federal	State
Administration, no. 1	$12,186.95	$5,791.42	$6,395.53
Printing and distribution of publications, no.1	1,014.38	1,014.38	....
County agents, no. 3	43,519.05	14,619.07	28,899.98
Home economics, no. 4	10,934.67	10,934.67	....
Extension schools and farmers' courses, no. 2	7,964.60	6,464.60	1,500.00
Boys' and girls' club work, no. 19	2,930.72	2,930.72	....
Farm management, no. 5	5,596.64	3,330.00	2,266.64
Farm crops, no. 6	3,450.06	1,600.06	1,850.00
Entomology, no. 7	5,262.02	1,762.02	3,500.00
Pomology, no. 8	1,449.88	1,449.88	....
Plant pathology, no. 9	5,978.85	3,840.00	2,138.85
Animal husbandry, no. 10	8,133.42	1,133.42	7,000.00
Soils, no. 11	6,110.00	3,110.00	3,000.00
Forestry, no. 12	142.57	142.57	....
Dairy, no. 13	1,550.00	350.00	1,200.00
Vegetable gardening, no. 14	3,305.38	1,749.84	1,555.54
Rural economy, no. 15	180.00	180.00	....
Rural engineering, no. 16	2,705.54	1,205.54	1,500.00
Poultry, no. 17	4,636.99	3,037.00	1,599.99
Landscape art, no. 20	796.66	796.66	....
Plant breeding, no. 21	1,998.24	1,998.24	....
Chemistry, no. 22	296.25	296.25	....
Home demonstration agents, no. 3a	4,670.19	4,670.19	....
Unexpended balance	214.78	107.39	107.39
Total	$135,027.84	$72,513.92	$62,513.92

New York State College of Agriculture at Cornell University
in account with
The United States and State Appropriations under the Smith-Lever Extension Act
1917–18

Dr.		Smith-Lever Funds		
		Total	Federal	State
To unexpended balance from 1916–17		....	....	....
Receipts from the United States and from State sources as per appropriations for fiscal year ended June 30, 1918, under act of Congress approved May 8, 1914 (Smith-Lever Act)		$135,027.84	$72,513.92	$62,513.92
Cr.	Abstract			
By Salaries	1	$111,831.62	$49,425.09	$62,406.53
Labor	2	1,437.56	1,437.56	....
Printing and distribution of publications	3	1,014.38	1,014.38	....
Stationery and small printing	4	3,559.62	3,559.62	....
Postage, telegraph, telephone, freight, and express	5	1,416.06	1,416.06	....
Heat, light, water, and power	6	....	....	....
Supplies	7	872.93	872.93	....
Library	8	23.15	23.15	....
Tools, machinery, and appliances	9	150.21	150.21	....
Furniture and fixtures	10	1,754.61	1,754.61	....
Scientific apparatus and specimens	11	611.25	611.25	....
Live stock	12	....	....	....
Traveling expenses	13	12,131.67	12,131.67	....
Contingent expenses	14	10.00	10.00	....
Unexpended balance	....	214.78	107.39	107.39
Total	....	$135,027.84	$72,513.92	$62,513.92

Summary Statement of Expenditures, by Projects, Showing Sources of Funds Used for Extension Work

Project	Total	Smith-Lever		College	State	County*	Other
		Federal	State				
Administration, no. 1	$26,223.85	$5,791.42	$6,395 53	$6,087.84	$7,274.00	....	$675.06
Printing and distribution of publications, no. 1.	23,132.83	1,014.38	....	537.20	....	$21,581.25	....
County agents, no. 3.	228,323.67	14,619.07	28,899.98	945.44	720.00	183,139.18	....
Home economics, no. 4..............	14,412.17	10,934.67	....	1,150.00	2,327.50	....	....
Extension schools and farmers' courses, no. 2.	19,076.56	6,464.60	1,500.00	4,304.10	6,807.86	....	....
Boys' and girls' club work, no. 19	3,359.65	2,930.72	....	....	428.93	....	....
Farm management, no. 5	7,930.02	3,330.00	2,266.64	....	2,333.38	....	....
Farm crops, no. 6...	3,450.06	1,600.06	1,850.00	....	....	....	....
Entomology, no. 7..	5,262.02	1,762.02	3,500.00	....	....	....	....
Pomology, no. 8....	2,803.89	1,449.88	....	104.01	1,250.00	....	....
Plant pathology, no. 9..............	7,340.00	3,840.00	2,138.85	....	1,361 15	....	....
Animal husbandry, no. 10	8,301.68	1,133.42	7,000.00	168.26	....	....	....
Soils, no. 11	6,710.00	3,110.00	3,000.00	....	600.00	....	....
Forestry, no. 12.	2,792.49	142.57	....	316.59	2,333.33	....	....
Dairy, no. 13	4,359.88	350.00	1,200.00	559.88	2,250.00	....	....
Vegetable gardening, no. 14.	3,508.97	1,749.84	1,555.54	203.59	....	....	....
Rural economy, no. 15..............	560.00	180.00	....	....	380.00	....	....
Rural engineering, no. 16	2,705.54	1,205.54	1,500.00	....	....	....	....
Poultry, no. 17	6,142.90	3,037.00	1,599.99	305.91	1,200.00	....	....
Fairs, no. 18.	439.12	....	....	439.12	....	....	....
Landscape art, no. 20	796.66	796.66	....	....	....	....	....
Plant breeding, no. 21..............	1,998.24	1,998.24	....	....	....	....	....
Chemistry, no. 22...	1,296.25	296.25	....	....	1,000.00	....	....
Home demonstration agents, no. 3a....	5,122.39	4,670.19	....	....	452.20	†	....
Total expenditures.........	$386,048.84	$72,406.53	$62,406.53	$15,121.94	$30,718.35	$204,720.43	$675 06
Unexpended balance.........	214.78	107.39	107.39	....	....	....	....
Total......	$386,263.62	$72,513.92	$62,513.92	$15,121.94	$30,718.35	$204,720.43	$675.06

* The " County " column includes all funds received and expended by county farm bureau associations from county appropriations, individuals, fees, and similar sources. These receipts are all turned in to one bank account, and it is therefore impossible to separate the expenditures.

† Figures not available for county funds used in this work.

Summary Statement of Expenditures, by Projects, Showing Classification of Expenditures From All Funds Used for Extension Work

Expenditures classified as	Total	Administration	Printing and distribution of publications	County agents	Home economics	Extension schools and farmers' courses	Home demonstration agents	Boys' and girls' club work	Farm management	Farm crops	Entomology	Pomology
Salaries	$201,271.82	$17,810.99		$99,344.01	$11,149.61	$9,427.05	$3,509.97	$3,019.65	$6,221.16	$2,850.00	$4,400.00	$2,400.62
Labor	2,068.64	631.08		1,053.22	256,89		66.98		2.85		38.00	
Printing and distribution of publications	23,132.83		$23,132.83									
Stationery and small printing	13,851.77	1,126.46		10,013.95	535.77	520.34	323.29	140.00	539.67	29.40	43.49	8.30
Postage, telegraph, telephone, freight, and express	15,136.80	440.58		13,084.70	57.81	472.45	119.35		252.96	19.86	105.16	6.97
Heat, light, water, and power												
Supplies	7,015.04	1.50		6,153.18	83.02	130.58	1.70	12.65	50.14		159 10	22.14
Library	42.88	19.73		2.75					4.40			
Tools, machinery, and appliances	150.21	2.85			4.05	16.55			0.30		6.99	26.62
Furniture and fixtures	8,479.27	526.49		6,366.51	316.53	129.53	548.57		307.06		18.50	87.58
Scientific apparatus and specimens	2,941.39	264.00		2,330.14		10.80						
Live stock												
Traveling expenses	77,676.82	5,289.67		55,814.34	2,008.49	8,359.26	552.53	187.35	551.48	550.80	490.78	251.66
Contingent expenses	34,281.37	110.50		34,160.87		10.00						
Total expenditures	$386,048.84	$26,223.85	$23,132.83	$228,323.67	$14,412.17	$19,076.56	$5,122.39	$3,359.65	$7,930.02	$3,450.06	$5,262.02	$2,803.89

Summary Statement of Expenditures by Projects (*continued*)

Expenditures classified as	Plant pathology	Animal husbandry	Soils	Forestry	Dairy	Vegetable gardening	Rural engineering	Rural economy	Poultry	Fairs	Landscape art	Plant breeding	Chemistry
Salaries	$6,600.00	$7,438.18	$6,060.00	$2,333.33	$3,800.00	$3,055.54	$2,305.54	$495.00	$5,601.17		$700.00	$1,500.00	$1,250.00
Labor		19.62											
Printing and distribution of publications													
Stationery and small printing	151.71	91.95	156.89			48.80		15.00	28.95		2.00	29.55	46.25
Postage, telegraph, telephone, freight, and express	35.38	65.44	86.63	0.35		48.33	42.75		258.14	$17.32	1.68	20.94	
Heat, light, water, and power													
Supplies	73.45	126.93	103.65	2.00			1.00		64.72		11.18	18.10	
Library	4.00						12.00						
Tools, machinery, and appliances	45.17	18.00	3.13				12.75				13.80		
Furniture and fixtures	70.80		5.70				42.50	50.00	9.50				
Scientific apparatus and specimens	6.79						262.66				67.00		
Live stock													
Traveling expenses	352.70	541.56	294.00	456.81	559.88	356.30	26.34		180.42	421.80	1.00	429.65	
Contingent expenses													
Total expenditures	$7,340.00	$8,301.68	$6,710.00	$2,792.49	$4,359.88	$3,508.97	$2,705.54	$560.00	$6,142.90	$439.12	$796.66	$1,998.24	$1,296.25

Summary Statement of Expenditures for Extension Work by Items of Expense and Sources of Funds, 1917–18

	Total	Smith-Lever		College	State	County	Other
		Federal	State				
Dr.							
To balance on hand	...	...	...	...	...	...	...
Receipts for 1917–18	$386,263.62	$72,513.92	$62,513.92	$15,121.94	$30,718.35	$204,720.43	$675.06
Cr.							
By Salaries	$201,271.82	$49,425.09	$62,406.53	...	$30,718.35	$58,721.85	...
Labor	2,008.64	1,437.56	...	$631,08	...	...	...
Printing and distribution of publication	23,132.83	1,014.38	...	537.20	...	21,581.25	...
Stationery and small printing	13,851.77	3,559.62	...	1,217.95	...	9,074.20	...
Postage, telegraph, telephone, freight, and express	15,136.89	1,416.06	...	1,158.25	...	12,562.49	...
Heat, light, water, and power	...	...	...	...	...	...	...
Supplies	7,015.04	872.93	...	...	...	6,142.11	...
Library	42.88	23.15	...	19.73	...	...	...
Tools, machinery, and appliances	150.21	150.21	...	...	...	...	...
Furniture and fixtures	8,479.27	1,754.61	...	787.39	...	5,937.27	...
Scientific apparatus and specimens	2,941.39	611.25	...	...	...	2,330.14	...
Live stock	...	...	...	...	...	...	...
Traveling expenses	77,676.82	12,131.67	...	10,659.84	...	54,210.25	$675.06
Contingent expenses	34,281.37	10.00	...	110.50	...	*34,160.87	...
Balance	214.78	107.39	107.39	...	...	...	...
Total	$386,263.62	$72,513.92	$62,513.92	$15,121.94	$30,718.35	$204,720.43	$675.06

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* The large " Contingent " item in the " County " column is due to the fact that the farm bureau associations of the State advanced nearly $25,000 last year from association funds for the purpose of carrying on their work pending the receipt of state funds. These items were regarded as a turnover by the association treasurers, and classified as " Miscellaneous."

Building Appropriations

Headquarters, Stock Judging, Agronomy and Forestry Buildings		$329,000.00
Expenditures heretofore reported	$322,084.59	
Expended July 1, 1917, to June 30, 1918	3,381.05	
		325,465.64
Balance unexpended		$3,534.36
Tool barn and sheep barn		$11,000.00
Expenditures heretofore reported	$8,464.33	
Expended July 1, 1917, to June 30, 1918	8.75	
		8,473.08
Balance unexpended		$2,526.92
Extending greenhouses		$30,000.00
Expenditures heretofore reported	$27,583.55	
Expended July 1, 1917, to June 30, 1918	2,416.45	
		30,000.00

Completion of heating plant, 1913 appropriation		$35,000.00
Expenditures heretofore reported	$34,049.22	
Expended July 1, 1917, to June 30, 1918	885.23	
		34,934.45
Balance unexpended		$65.55
Completion of heating plant, 1915 appropriation		$35,000.00
Expenditures heretofore reported	$28,668.57	
Expended July 1, 1917, to June 30, 1918	6,285.95	
		34,954.52
Balance unexpended		$45.48
Plans for Plant Industry Building		$7,500.00
Expended July 1, 1917, to June 30, 1918		3,000.00
Balance unexpended		$4,500.00
Piggery with detached pens		$7,000.00
Expenditures heretofore reported	$8.35	
Expended July 1, 1917, to June 30, 1918	6,990.65	
		6,999.00
Balance unexpended		$1.00
Additional unit to heating plant		$12,000.00
Expenditures heretofore reported	$9.35	
Expended July 1, 1917, to June 30, 1918	8.75	
		18.10
Balance unexpended		$11,981.90
Storage shed		$200.00
Expended July 1, 1917, to June 30, 1918		200.00
Packing shed		$1,000.00
Expended July 1, 1917, to June 30, 1918		1,000.00
Addition to shed, plant-breeding field		$400.00
Expended July 1, 1917, to June 30, 1918		393.28
Balance unexpended		$6.72
Storage cellar		$200.00
Expended July 1, 1917, to June 30, 1918		193.90
Balance unexpended		$6.10
Water pipe line		$200.00
Expended July 1, 1917, to June 30, 1918		196.50
Balance unexpended		$3.50
Sidewalks, roads, and drains		$5,000.00
Expended July 1, 1917, to June 30, 1918		4,665.08
Balance unexpended		$334.92

Conclusion

The foregoing pages give in brief an account of some of the interesting and significant activities of the New York State College of Agriculture during the year 1917–18. The limits of space have forced the omission of many important data that it would have been worth while to record. While fully realizing the necessity of maintaining the teaching and research with as little interruption of customary standards as possible, the College has been impelled, during the first year of our participation in the war, with the spirit of public service and the desire to more than fulfill its obligations to the agricultural interests of the State in accordance with its legal requirements. Much has been accomplished; but, great as the accomplishment has been, it represents only a fraction of the service which larger funds would have made possible. In a time when every agency, public and private, must be devoted unsparingly to the public good and to the strengthening of the Nation, the State College of Agriculture is eager to have its staff and its facilities utilized to the utmost.

Respectfully submitted,
A. R. MANN,
Dean, New York State College of Agriculture.

JUNE, 1918 MEMOIR 12

CORNELL UNIVERSITY

AGRICULTURAL EXPERIMENT STATION

LYSIMETER EXPERIMENTS

RECORDS FOR TANKS 1 TO 12 DURING THE YEARS 1910 TO 1914 INCLUSIVE

T. LYTTLETON LYON AND JAMES A. BIZZELL

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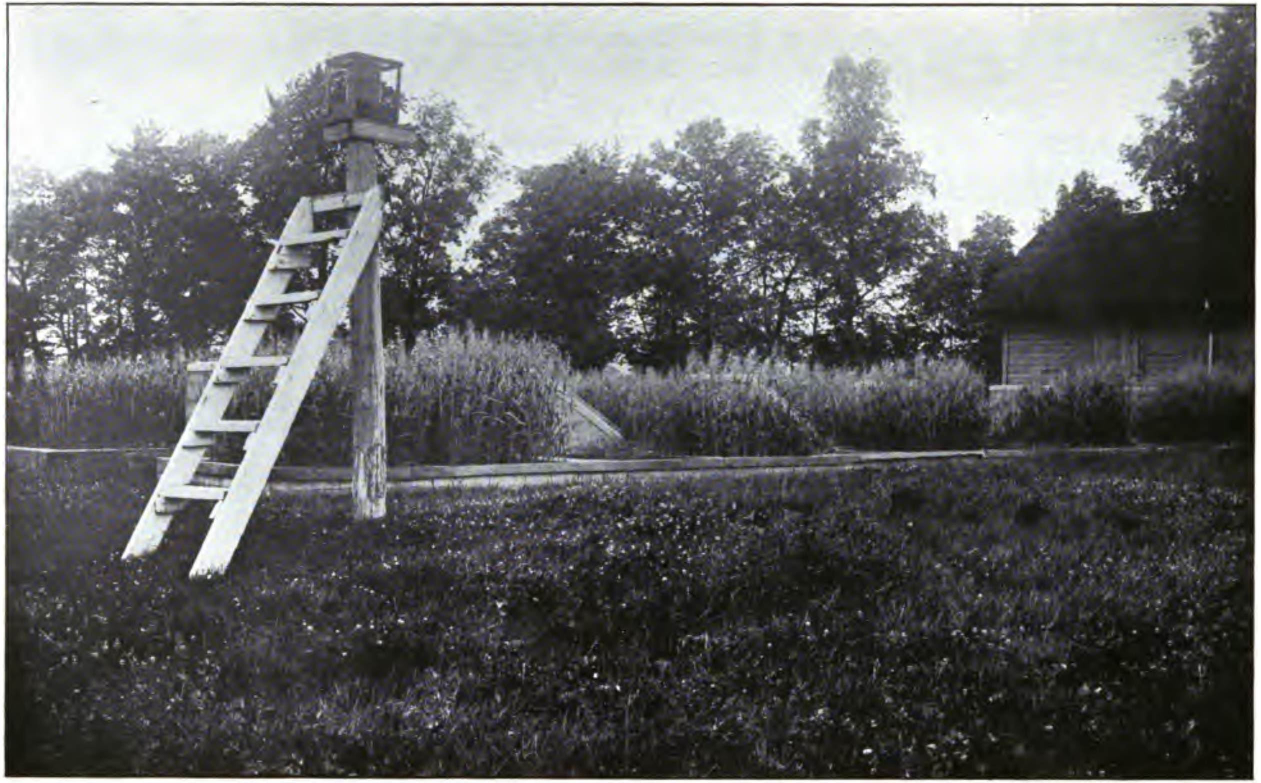
LYSIMETER EXPERIMENTS

RECORDS FOR TANKS 1 TO 12 DURING THE YEARS 1910 TO 1914 INCLUSIVE



LYSIMETERS, HEAD HOUSE, AND RAIN GAUGE

LYSIMETER EXPERIMENTS

RECORDS FOR TANKS 1 TO 12 DURING THE YEARS 1910 TO 1914 INCLUSIVE

T. Lyttleton Lyon and James A. Bizzell

The experience of farmers in many parts of New York State, and also in other humid areas thruout the country, has indicated a tendency for the soil to become acid with prolonged cultivation. Land that formerly produced satisfactory crops of red clover gradually has become incapable of doing so. Both experiment station results and farm experience have shown that the ability to raise clover may be restored to these soils by applications of lime. The acid condition of the soil has been attributed, in part at least, to the removal of calcium and other bases in crops and in drainage water. The extent of the removal in crops has frequently been measured, but of the removal in drainage water less is known.

The present experiment was designed to ascertain the extent to which, and some of the conditions under which, calcium is removed in drainage water and in crops from one or two rather prevalent soil types, and at the same time to study certain of the changes that accompany the loss of calcium. With this in view, the removal of magnesium, potassium, sodium, nitrogen, sulfur, phosphorus, and a few less important elements, has been determined, in order to discover the relations between these substances and to ascertain whether substitutions of one for another occur in the soil with release in the drainage water of the replaced constituent.

Twelve tanks, the records of which for five years are here published, were used in a study of certain systems of cropping in their effect on the loss of calcium and the accompanying changes, and also of the effect on these changes of the application of burnt lime and of potassium sulfate fertilizer. Incidentally data were accumulated also on the relation of percolation to rainfall and of certain methods of soil treatment to percolation.

Acknowledgment.— The authors wish to express their thanks to Mr. E. W. Leland for his services in measuring and sampling the drainage water during the entire period of the experiment, and for supervising the cultural operations on the tanks and the plats.

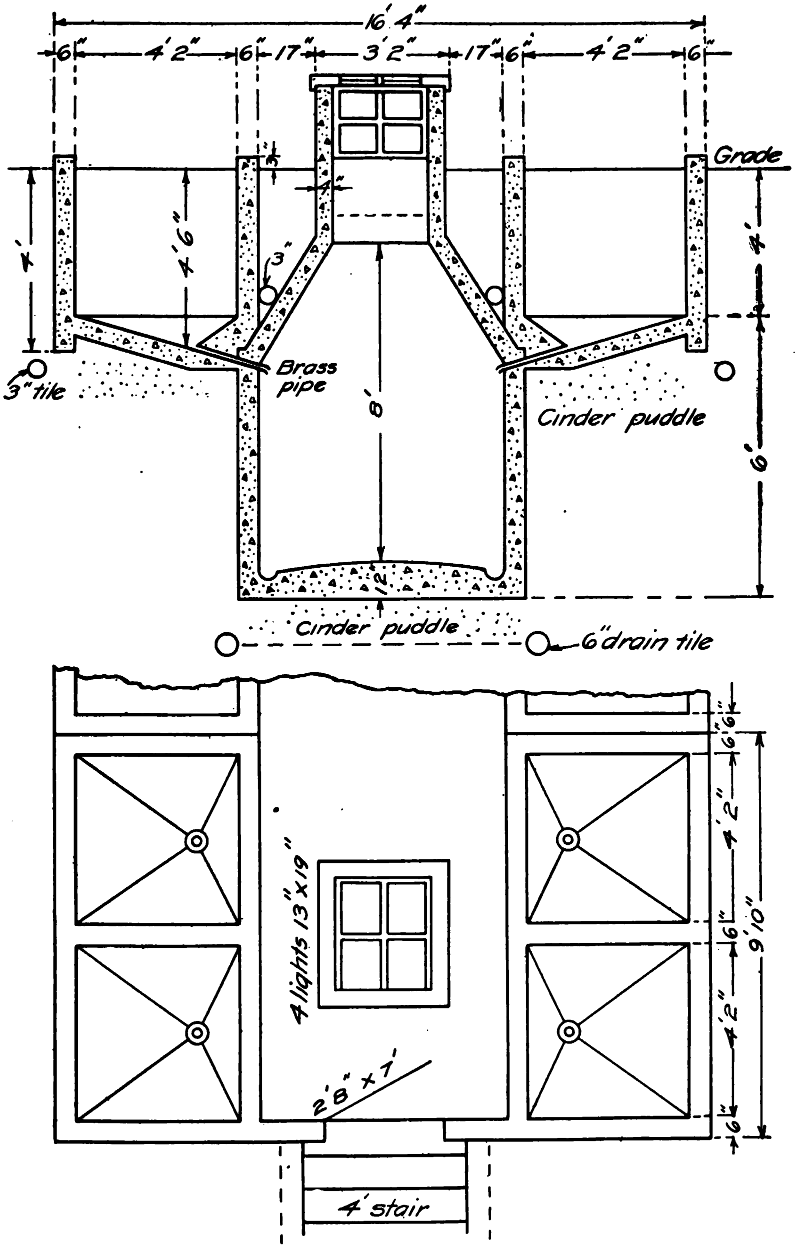


FIG. 1. CONSTRUCTION OF LYSIMETERS

Upper diagram, vertical section of tanks and tunnel
Lower diagram, plan of tanks, showing location of outlet pipes

THE LYSIMETERS AND THEIR TREATMENT

Construction of the lysimeters

The lysimeters are built of concrete. Each tank is 4 feet and 2 inches square, with sides 4 feet and 3 inches deep and with a funnel-shaped bottom. There are twenty-four tanks, arranged in two rows of twelve each. The rows are 6 feet apart. Between the rows is a tunnel 6 feet wide, the bottom of which is 10 feet below the top of the tanks. From the lowest point in the bottom of each tank a drainpipe leads into the tunnel, where receptacles are placed to catch the drainage water.

The surface of the soil in the tanks is level with the surrounding soil of the field. The walls of the tanks do not form the inside walls of the tunnel, but there is soil between these walls which is intended to reduce conduction of heat from the tunnel to the soil of the tanks.

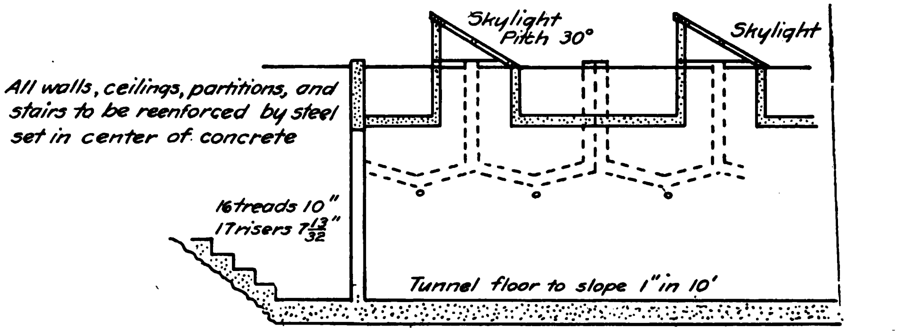

Skylight Pitch 30°
Skylight
All walls, ceilings, partitions, and stairs to be reenforced by steel set in center of concrete
16 treads 10"
17 risers 7$\frac{13}{32}$"
Tunnel floor to slope 1" in 10'

FIG. 2. VERTICAL SECTION OF TUNNEL, WITH SIDES AND BOTTOMS OF TANKS INDICATED BY DOTTED LINES

Before soil was placed in the tanks the walls were covered with waterproofing asphaltum to prevent the soil water from taking up any calcium from the concrete. The tops of the tank walls are covered with sheet iron, which extends down the sides 5 or 6 inches to protect the asphaltum during tillage operations.

The drainpipe is made of brass, lined with tin, and is 2 feet long and 2 inches in diameter. It is made large enough to permit of easy cleaning and has no bend. The tube has a removable cap on the lower end, and into the middle of this cap is fixed a steel rod which runs to within 4 inches of the upper end of the tube, where it supports a perforated cone. Between this cone and the sand in the tank, gravel is placed to support the sand and facilitate drainage. The cap, the rod, and the cone may all be removed if the outlet becomes clogged, but it has never been necessary to do this. From the lower side of the drainage tube a smaller tube projects, and over this is drawn a rubber tube to conduct the water to the receptacles in the tunnel.

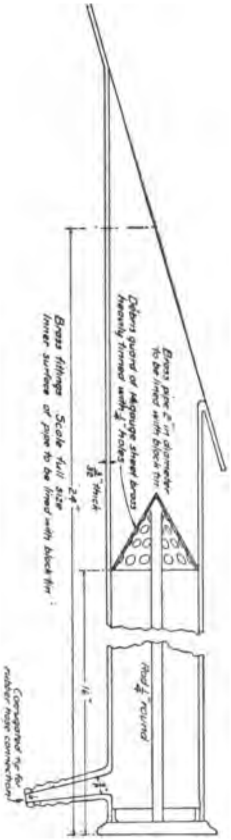
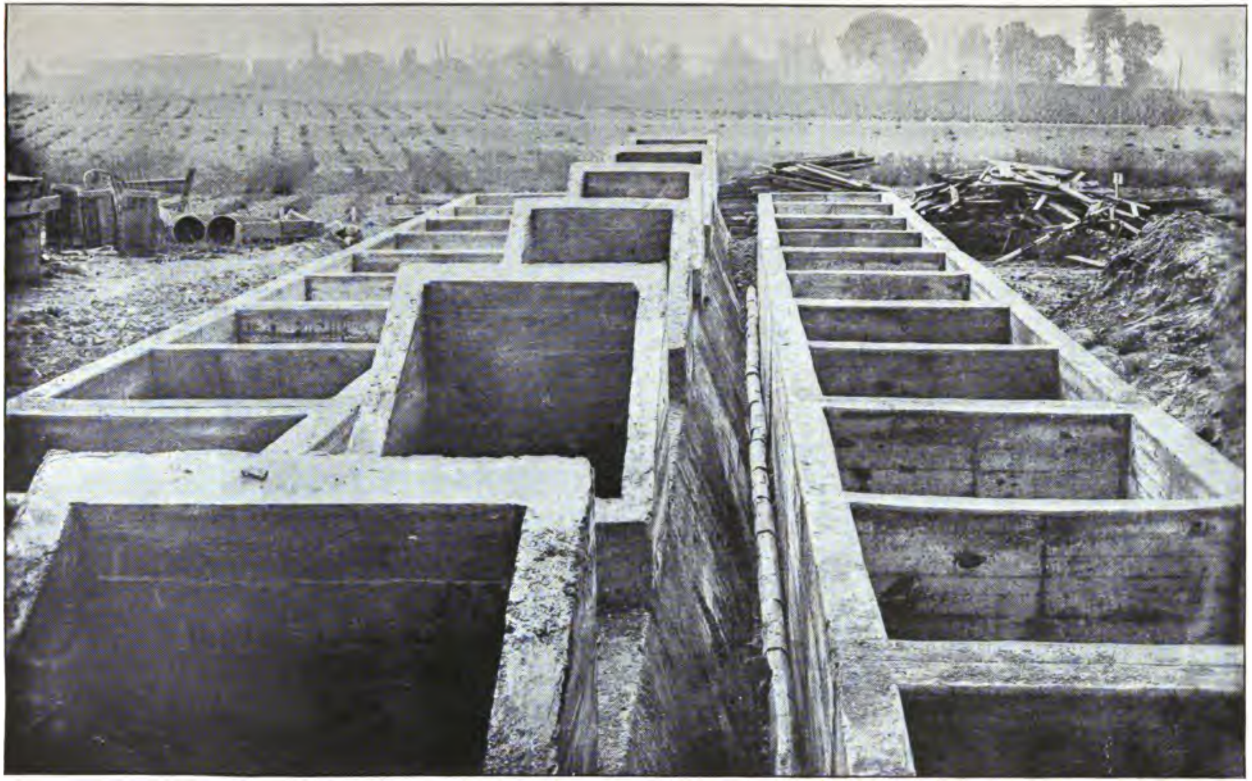

Brass pipe 2" in diameter to be lined with block tin
Debris guard of 16 gauge sheet brass heavily tinned with 1/4" holes
1/32" thick
24"
Brass fittings Scale full size
Inner surface of pipe to be lined with block tin
16"
Rod 1/4" round
Corrugated tip for rubber hose connection

Fig. 3. vertical section of drainpipe

The drainage water is caught in galvanized iron cylinders, of which there are two for each tank. One cylinder has a side tube near the top which fits into a hole in the one next it, so that when the first cylinder becomes full the water may flow into the other. The cylinders are of such a diameter that each centimeter in depth represents 800 cubic centimeters of volume, and each cylinder holds about 60 liters. The drainage is measured by running a meter stick into the cylinder and measuring the height of the water. The volume is then easily computed by multiplying the number of centimeters of depth by 800, to get the number of cubic centimeters. An aliquot sample is then removed and the remainder of the water is allowed to run off thru a faucet in the bottom of the cylinder. The waste water is conducted by gutters in the tunnel to drains which carry it away. The samples for analysis are placed in milk cans lined with paraffin. An antiseptic is always kept in these sample cans.

The soil used

Tanks 1 to 12, which were the ones used in this experiment, were filled during the summer of 1909 with soil from Caldwell Field on the university farm, the soil being excavated to a depth of 4 feet in layers of 1 foot. These layers were placed in the tanks in the order in which they were present in the field, the funnel-shaped bottom having previously been filled with sand. In each tank 3½ tons of soil was placed, being tamped



LYSIMETERS UNDER CONSTRUCTION

The illustration shows the space for soil between the walls of the tunnel and those of the tanks. The drain tiles serve to remove the rain water that might otherwise accumulate in this space

down during the process. It was unnecessary to dispose of stones as there were none in the soil. After the bottom 2 feet of soil had been placed in the tanks, 60 gallons of water was run into each to settle the contents. When the tanks were filled, the soil came to within 3 inches of the tops. There has been very little settling in the cropped tanks, but those that were kept free of vegetation have sunk 2 or 3 inches. As the average weight of soil in a tank was 7133 pounds and the volume occupied was about 74 cubic feet, the weight per cubic foot of the moist soil was about 96.4 pounds. The average weight of each foot of soil placed in the tanks, and the moisture content, are given in table 1:

TABLE 1. AVERAGE WEIGHT OF EACH TWELVE-INCH LAYER OF SOIL IN TANKS, AND ITS MOISTURE CONTENT

	First foot	Second foot	Third foot	Fourth foot
Weight of moist soil (in pounds)	1,700	1,768	1,883	1,792
Moisture in soil (in per cent of dry soil)	16.6	15.5	17.9	20.1
Weight of dry soil (in pounds)	1,458	1,531	1,597	1,492
Weight of dry soil per acre foot (in pounds)	3,645,000	3,827,500	3,992,500	3,710,000

The soil has been classified by the United States Soil Survey as Dunkirk clay loam. A statement of the mechanical analysis of the soil placed in the tanks is contained in table 2. It is a heavy, compact soil, and requires careful management in the field to keep it from puddling. How-

TABLE 2. MECHANICAL COMPOSITION OF SOIL IN FIELD FROM WHICH TANKS 1 TO 12 WERE FILLED

Kind of soil	First foot (per cent)	Second foot (per cent)	Third foot (per cent)	Fourth foot (per cent)
Fine gravel	0.40	0.13	0.07	0.08
Coarse sand	0.63	0.37	0.27	0.18
Medium sand	0.83	0.52	0.33	0.28
Fine sand	1.85	1.05	1.05	1.10
Very fine sand	12.90	11.27	7.25	5.18
Silt	60.83	53.95	52.42	56.50
Clay	22.63	32.72	38.62	36.67

ever, during the five-years period embraced by these experiments there has been no stoppage of the outlets nor failure of the soil to drain properly. The drainage water has usually come thru entirely free from sediment. Only in the springtime, when the soil is thawing, has there been any tendency for the soil particles to come thru the pipes.

The chemical composition of the soil placed in tanks 1 to 12, as determined by averaging the results of the analysis of six samples, is given in table 3. These were bulk analyses. The methods of making them are stated in the appendix, pages 85 to 87.

TABLE 3. CHEMICAL ANALYSIS OF SOIL PLACED IN TANKS 1 TO 12

Constituents determined	First foot	Second foot	Third foot	Fourth foot
Nitrogen (per cent)	0.134	0.062	0.064	0.054
Organic carbon (per cent)	1.190	0.300	0.150	0.140
Calcium oxide (per cent)	0.340	0.280	0.490	1.530
Magnesium oxide (per cent)	0.350	0.450	0.530	0.590
Potassium oxide (per cent)	1.830	2.360	2.610	2.480
Sodium oxide (per cent)	0.860	0.860	0.760	0.820
Phosphoric anhydride (per cent)	0.084	0.079	0.110	0.131
Sulfur trioxide (per cent)	0.084	0.053	0.055	0.054
Carbon dioxide (per cent)	0.030	0.020	0.050	2.680
Lime requirement (CaO in parts per million)	1,222	1,285	516	0
Lime requirement (CaO in pounds per acre foot*)	4,454	4,918	2,060	0

* Calculated from weights of soil given in table 1.

The soil consists of glacial material reworked by streams and redeposited from glacial lakes. Owing to its sedimentary origin it is comparatively free from stones; the mass of soil used for this experiment contained no stones. In the production of crops the soil responds well to applications of manure and to commercial fertilizers. It is also benefited by lime. Its degree of responsiveness to lime is expressed by the fact that it will raise a fair crop of red clover without the addition of lime, but alfalfa is a practical failure when no lime has been applied.

The crops to which this soil is best suited are the small grains, particularly wheat, and such grasses as timothy and bluegrass. Timothy responds remarkably well to fertilizers on this soil. Maize and potatoes are not very successfully produced as the soil is too heavy for crops of that kind.

Manure and fertilizers used

Farm manure was applied twice to the soil in each of the twelve tanks, the unplanted soil receiving the same treatment as the cropped. Each application was at the rate of ten tons to the acre. The first application was made in the spring of 1910, before the first crop was planted, and the second in the spring of 1914. The analyses of the manure are given in table 4:

TABLE 4. COMPOSITION OF FARM MANURE APPLIED TO THE SOIL IN TANKS 1 TO 12

Constituents	Manure applied in 1910		Manure applied in 1914	
	Percentage composition	Pounds per acre	Percentage composition	Pounds per acre
Dry matter	76.72	15,344	77.44	15,488
Nitrogen	0.61	122	0.42	84
Phosphoric anhydride	0.41	82	0.24	48
Sulfur trioxide	....	....	0.19	38
Potassium oxide	0.77	154	0.45	90
Calcium oxide	0.48	96	0.64	128
Magnesium oxide	....	....	0.22	44

The sulfate of potash applied annually to tanks 11 and 12 during the years 1910 to 1912 contained 51.63 per cent of K_2O, and that applied in 1913 and 1914 contained 51.42 per cent of K_2O.

The burnt lime, of which only one application was made, contained 91.95 per cent of CaO and a trace only of MgO.

Soil treatment and cropping systems

As previously stated, the tanks were all filled with soil in the summer of 1909. This operation occupied most of the summer, and no tanks were planted that year except tank 1, which was filled at a sufficiently early date to permit of its being so used. Tank 2, which was filled at the same time as tank 1, was kept bare and the drainage water from these two tanks was collected. The use of these tanks was started a year in advance of the others in order to test the practicability of the apparatus. It was not known whether such a large mass of very compact soil would allow the rainfall to percolate readily, and it was also desired to take some samples of the soil from time to time to see whether nitrate formation proceeded in a normal manner in the surface soil. As the apparatus appeared to work satisfactorily, the remaining ten tanks were filled in the course of the summer, and drainage water was collected during the following winter. In the discussion of results the data from tanks 1 and 2 usually are not included, because they do not cover the same period as do the remainder of the tanks, and they have been used from time to time to test ways of employing the apparatus. A statement of the soil treatment of each tank, and of the crops raised, is given in table 5:

TABLE 5. SOIL TREATMENT AND CROPS RAISED ON LYSIMETER TANKS 1 TO 12, DURING THE PERIOD FROM 1910 TO 1914

Tank	Soil treatment		Crops raised			
	Fertilizer	Lime	1910	1911	1912	1913 and 1914
1.......	Farm manure	None......	Maize....	Oats.....	Wheat...	Timothy
2.......	Farm manure	None......	None....	None....	None....	None
3.......	Farm manure	None......	Maize....	Oats.....	Wheat...	Timothy
4.......	Farm manure	None......	None....	None....	None....	None
5.......	Farm manure	None......	Maize....	Oats.....	Wheat...	Timothy and clover
6.......	Farm manure	None......	Oats.....	Grasses...	Grasses...	Grasses
7.......	Farm manure	Burnt lime..	Maize....	Oats.....	Wheat...	Timothy
8.......	Farm manure	Burnt lime..	None....	None....	None....	None
9.......	Farm manure	Burnt lime..	Maize....	Oats.....	Wheat...	Timothy and clover
10.......	Farm manure	Burnt lime..	Oats.....	Grasses...	Grasses...	Grasses
11.......	Farm manure, potassium sulfate	None......	Maize....	Oats.....	Wheat...	Timothy
12.......	Farm manure, potassium sulfate	Burnt lime..	Maize....	Oats.....	Wheat...	Timothy

The applications of farm manure were made in the spring of 1910 and in the spring of 1914. Both applications were at the rate of 10 tons per acre, and were given to the tanks that were never planted as well as to the cropped tanks. The applications of potassium sulfate were made annually to tanks 11 and 12, at the rate of 200 pounds per acre. No lime was applied to tanks 1 to 6 or to tank 11. In the spring of 1910 burnt lime was applied to tanks 7, 8, 9, 10, and 12, at the rate of 3000 pounds per acre.

Tanks 2, 4, and 8 were never planted to any crop, and all vegetation was prevented from growing on them by hoeing. In the year 1910, when maize was growing on most of the other tanks, the unplanted tanks were hoed at the same time and in the same way as were the tanks planted to maize; when other crops were growing on the planted tanks, the unplanted ones were merely scraped with a hoe. In each tank planted to maize there were four hills of maize with three plants in a hill. Seven rows of oats and seven rows of wheat were sown in each tank planted to those crops. On tanks 6 and 10, oats were planted in 1910, and a mixture of grasses, consisting of timothy, Kentucky bluegrass, and redtop, was sown with the oats. These tanks were then kept permanently in these grasses. In 1914 there was a notably smaller proportion of bluegrass and a larger proportion of timothy and redtop on the unlimed soil (tank 6) than on the limed soil (tank 10).

Timothy was seeded with the wheat in the fall of 1911 on tanks 1, 3, 5, 7, 9, 11, and 12, and in the spring of 1912 clover also was seeded on tanks 5 and 9. All crops grew excellently, but much of the wheat was winterkilled and the crop was cut for hay about the time it headed, and another crop mixed with timothy was cut later in the summer. Both timothy and clover germinated well and grew vigorously in 1913. The clover, however, failed to make an appearance in 1914 on either tank 5 or tank 9. The yields of crops for each tank are given in table 1 in the appendix (page 92).

Corresponding field plats

A set of field plats of 1/100 acre each were laid out in the same field as that from which soil was obtained for tanks 1 to 12, and on these the treatments given the tank soil were repeated. The reason for conducting the experiments on the field plats as well as in the lysimeter tanks was to ascertain whether the effect of the lime and fertilizer applications on the lysimeter soil corresponded to the effect on the soil in the field. It was thought also that an opportunity might thus be given to compare the changes that take place in the lysimeter soils with those that occur under field conditions.

QUANTITY AND RATE OF PERCOLATION

The proportion of the rainfall that finds its way thru a soil may be expected to vary with a number of attendant conditions. Not only may these conditions be different in widely separated parts of the world, but even in a given locality they change from time to time, or with different soils, so that it is impossible to assign any definite ratio of percolate to rainfall. The percolate is merely that part of the rainfall that is absorbed by the soil and not returned to the atmosphere by evaporation from the surface or by transpiration from plants. All the factors that affect evaporation and transpiration therefore influence percolation, altho in the opposite way. It is of interest, and perhaps may be useful, to know how much of the rainfall passed thru the soil that remained bare for five years and how much passed thru the planted soil, in order to compare these figures with similar data obtained elsewhere.

Percentage percolation of rainfall

The figures for the flow from each of the lysimeter tanks, expressed in liters for each month from May 1, 1910, to April 30, 1915, are given in table 2 of the appendix (pages 93–94). The flow calculated to acre inches annually for the same period is given in table 3 of the appendix (page 95). These tables furnish the data from which may be found the average annual percolation in inches from the unplanted soil and also from the soil on which crops grew. This, together with the percentage percolation, is stated in table 6. The rainfall during the five-years period averaged 31.14 inches annually.

TABLE 6. AVERAGE ANNUAL PERCOLATION OF RAINFALL FROM UNPLANTED AND FROM PLANTED SOIL DURING FIVE-YEARS PERIOD

Tanks	Crop treatment	Average annual percolation	
		Inches	Per cent of rainfall
4, 8	No plants allowed to grow	24.40	78.35
3, 5, 6, 7, 9, 10, 11, 12	Plants raised every year	16.96	54.46
	Difference in percolation	7.44	23.89

On the basis of these figures, about three-fourths of the rainfall percolated thru the bare soil and one-half thru the cropped soil. As the proportion of percolate depends on the character of the soil and on the weather conditions, these data should accompany a statement of the percolation. The physical properties of the soil under experiment have already been described. The air temperatures at Ithaca, the hours of sunshine, the average hourly velocity of the wind, and the humidity of the air, are stated in table 4 of the appendix (pages 96–98). No records of evaporation for a free water surface have been kept at Ithaca, but such data have been collected by the City Department of Engineering at Rochester, New York, and these arranged by monthly averages are given in table 5 of the appendix (page 98). In order to judge how closely these data collected at Rochester are applicable to Ithaca, the rainfall, the air temperature, and the air humidity at Rochester and at Ithaca[1] are given in table 6 of the appendix (page 99).

It is seen from table 5 of the appendix that the evaporation from the floating tub was 32.29 inches annually and that from the exposed tub was 45.65 inches; while the rainfall for the same period was 27.89 inches at the place where the evaporation records were taken, altho the Weather Bureau readings at Rochester totaled 32.47 inches annually for the same period. In either case the evaporation from the free water surface was as great as or greater than the rainfall. The effect of the soil, therefore, is to conserve moisture. A region that has no underground drainage must have a very large rate of evaporation as compared with the rainfall.

July is the month of greatest rate of evaporation and, except when the ground is frozen, the month of least percolation, and August falls very little behind in either respect. It is worthy of note, however, that there is almost always some percolation from the unplanted soil thruout the summer, altho the evaporation during that time is more than double the rainfall (tables 2 and 5 of the appendix, pages 93–94 and 98).

Experiments by other observers.— It may be of some interest to compare the percentage percolation as found by the writers with that obtained by some other observers. The percentage of the annual precipitation that passes thru the soil, both when the soil is planted and when it is bare of vegetation, has been determined at a number of localities. The most complete data on this subject have been obtained at the Rothamsted Experimental Station, Harpenden, England. The lysimeters at that station were built around columns of soil and a perforated iron sheet was driven under each one to form a bottom. The soil therefore has not been greatly disturbed. It is a rather heavy loam and is kept free of vegetation. There are three lysimeters, representing depths of 20, 40, and 60 inches, and for the twenty-four years from September, 1877, to August, 1901, the percolation according to Miller (1903)[2] was, respectively, 50, 53.2, and 50.1 per cent of the rainfall. The maximum and the minimum drainage occur, respectively, in November and in June.

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[1] The authors are indebted to Mr. John F. Skinner for the compiled data on evaporation and weather at Rochester, and to Professor W. M. Wilson for the weather records at Ithaca.

Four years later Miller (1906) again reported on the flow from these lysimeters, and included the records from 1870, when the gauges were installed, up to 1905, a period of thirty-five years. The average rainfall for the period was 28.97 inches, of which 47.8 per cent passed thru the 20-inch gauge, 50.4 per cent thru the 40-inch gauge, and 47.1 per cent thru the 60-inch gauge. The fall and winter months show the greatest percolation, and the summer months the least. This is true of the percentage percolation as well as the absolute.

An early report on the drainage from the Rothamsted lysimeters was made by Gilbert (1876), whose figures indicate that from September, 1870, to August, 1875, inclusive, the average annual rainfall was 27.93 inches, of which 36.8 per cent passed thru the 20-inch gauge, 36 per cent thru the 40-inch gauge, and 28.6 per cent thru the 60-inch gauge. A comparison of the observations made by Gilbert with those of Miller lead to the conclusion that the percentage percolation, as well as the absolute, increased very materially after the first five years. It is a common observation that tile drains in heavy soil run more freely after they have been in operation for a few years.

The more recent European experiments dealing with the proportion of rainfall that percolates thru the soil, may be considered to have begun with those of Wollny (1888) at Munich, Germany. He reviews the previous work on this subject, which is here summarized in table 7.

By means of metal lysimeters Wollny studied the effect of certain physical conditions of the soil on percolation. He used cylinders of two sizes. The smaller cylinders had an area of 400 square centimeters and were 30 centimeters deep; the larger ones were 1000 square centimeters in area and had a depth of 50 centimeters. In some of his experiments he used soil, and in others he used quartz sand of different degrees of fineness. He concluded that: (1) the finer the particles, the less is the percentage percolation; (2) there is more percolation thru a crumbly soil than thru one with a separate grain structure; (3) there is more percolation thru a loose soil than thru a compact soil; (4) the presence of stones increases percolation; (5) percolation is greatest thru sand, next thru peat, and least thru loam.

---

[2] Dates in parenthesis refer to bibliography, pages 82–84.

TABLE 7. Results of Experiments in the Percolation of Rainfall thru Soil, as Summarized by Wollny

Observer	Place	Kind of soil	Crop	Depth of soil (centimeters)	Rainfall (millimeters)	Drainage (per cent of rainfall)
Dalton	Manchester, England	Not known	Grass	91.4	827	25.1
Dickinson	Abbotshill, England	Sandy loam	Grass	91.4	659	42.3
Charnock	Holmfield, England	Dolomite soil	Grass	91.4	625	19.6
Greaves	Lee Bridge, England	Sand	None	91.4	653	83.2
Greaves	Lee Bridge, England	Loamy sand	Grass	91.4	653	26.6
Gilbert	Rothamsted, England	Heavy loam and clay	None	101.6	788	43.4
Maurice	Geneva, Switzerland	Not known	?	?	660	39.0
Risler	Calèves, Switzerland	Clay	With	120.0	1,050	28.0
Möllendorf	Görlitz, Germany	Clay	None	125.0	652	28.1
Möllendorf	Görlitz, Germany	Loam	None	125.0	652	41.0
Möllendorf	Görlitz, Germany	Sandy loam	None	125.0	652	40.5
Möllendorf	Tharand, Germany	Clay	With	125.0	739	40.8
Möllendorf	Tharand, Germany	Loam	With	125.0	739	58.7
Pfaff	Erlangen, Germany	Sand	None	63.0	....	43.0
Woldrich	Salzburg, Germany	Sandy loam and clay	With	63.0	768	33.9
Woldrich	Salzburg, Germany	Sandy loam and clay	None	63.0	768	64.2
Woldrich	Oberdöbling, Germany	Loam	None	126.4	654	32.8
Ebermayer	Munich, Germany	Not known	None	116.7	865	53.0

Ebermayer (1890) conducted experiments at Munich in concrete tanks, each of which had an area of 4 square meters and a depth of 120 centimeters. There were five tanks, each of which was filled with a different soil and none of which were cropped. The soils used were (1) a whitish gray gravelly quartz sand, (2) a red fine-grained quartz sand, (3) a friable loam, (4) a limestone sand with nearly half its particles over 2 millimeters in diameter, and (5) dark muck. Observations were made on the rainfall and on the volume of drainage water for the four years from 1881 to 1884. The average yearly rainfall for the period was 131.6 millimeters, or 51.8 inches. The percentage percolation was as follows: Lysimeter no. 1, 85 per cent; no. 2, 107 per cent; no. 3, 94 per cent; no. 4, 43 per cent; no. 5, 39 per cent. The excess of percolate over rainfall in lysimeter no. 2, Ebermayer accounts for by presuming a condensation of atmospheric humidity on the surfaces of the soil particles. The percentage percolation was in every case greater in winter than in spring, in summer, or in autumn.

Very extensive experiments were conducted by Dehérain (1902) at Grignon, France. His most conclusive experiments were performed in concrete tanks, each of which was 2 meters square and 1 meter deep and contained 5 tons of soil. The results that he considers representative are for the year 1892–93. With a rainfall of 23 inches there was an average of 23.2 per cent in the drainage water thru several soils, on all of which crops were raised.

Creydt, Von Seelhorst, and Wilms (1901) measured the water that was conducted thru tile drains from an area of 4.81 hectares of a loam soil overlying a clay loam. The tiles were 1.25 meters deep and 15 meters apart. The land was planted to beans in 1899 and to beets in 1900. For the period from July 28, 1899, to August 10, 1900, the total rainfall amounted to 5739 liters per hectare and the drainage water to 5027 liters per hectare. The percolation was therefore 87.6 per cent of the rainfall. Calculated for the year from July 28, 1899, to July 27, 1900, the rainfall was 21⅔ inches.

Large iron cases from which drainage can be collected have been installed at the Göttingen Experiment Station. These have a surface area 1 meter square, and a depth of 1.25 meters. They may also be weighed. Von Seelhorst (1906 a) reports an experiment in which certain of these cases were filled with a loam and others with a sandy soil. All were kept bare of vegetation. For the calendar year 1905 the rainfall was 30 inches. The percolation thru the loam soil was 51.47 per cent of the rainfall, and thru the sandy soil 57.08 per cent. The mean annual air temperature for the year was 51.2° F., and the mean for the months of June, July, and August was 70.9° F. Drainage as a rule was greater from the sandy soil than from the loam.

At the Bromberg Agricultural Institute are large lysimeters each having a diameter of 2 meters and a depth of 1.2 meters. Experiments were reported by Gerlach (1910 a), in which soils from five fields were used, one portion of each being fertilized and one unfertilized. The experiment began on June 1, 1906, and ended on July 29, 1909. The first year there was no crop, the second year potatoes were raised, the third year oats, and the fourth year rye. During the 1155 days of the experiment the rainfall was 1689.9 millimeters, or at the rate of 21.15 inches annually. Of this the following percentages passed thru the soils:

Kind of soil	Percentage of rainfall in drainage	
	Fertilized soil	Unfertilized soil
Muck soil	9.7	9.7
Loamy sand, poor in humus	16.3	21.1
Sandy loam, high in humus	27.6	27.0
Loamy sand, poor in humus	7.6	7.1
Yellow sandy loam	9.6	11.6

It would appear from these results that the loamy soils permitted of greater percolation than the sandy soils.

At the Bromberg Agricultural Institute lysimeter experiments were conducted by Krüger (1911) in 1910. The character of the soil is not stated. Some of the lysimeters were kept bare of vegetation, others were planted to rye. On the fallow soil 55 per cent of the rainfall percolated thru, on the cropped soil from 20 to 25 per cent. The amount of rainfall is not stated.

At Jönköping, in Sweden, lysimeter experiments were conducted by Von Feilitzen, Lugner, and Hjerstedt (1912). The lysimeters each had a surface area 80 centimeters square, and a depth of 50 centimeters. They were all filled with muck soil containing about 60 per cent of organic matter. During the first year of the experiments the soil in all was kept bare of vegetation. In the following years one set of tanks was planted to a rotation of crops and another set was kept in grass. The fallow soil allowed 63 per cent of the rainfall to percolate, while 35 per cent passed thru the soil that was cropped. The amount of rainfall is not stated.

Experiments have been conducted in India with lysimeters similar to those used at Rothamsted, England. Hayman and Burt (1906) report that from June 1, 1904, to May 31, 1905, the rainfall at Cawnpore was 49.2 inches, and the percolation from one 6-foot gauge was 21.78 inches, or 44.3 per cent of the rainfall. The percolation from the two 3-foot gauges showed such a great discrepancy that year that the figures are hardly worth quoting; but Burt and Leather (1909) report that for the year ending May 31, 1909, the rainfall was 31.53 inches, of which 14.15 inches, or 44.9 per cent, percolated thru one of the 6-foot gauges, and 13.95 inches, or 44.2 per cent, thru the other. The drainage from the two 3-foot gauges amounted to 48.1 and 49.8 per cent of the rainfall, respectively.

At the Texas Experiment Station, lysimeter experiments have been conducted by Fraps (1914). The lysimeters consist of galvanized iron cans 12 inches in diameter and 24 inches deep, and are buried in the ground. Eight different soils were used. The total quantity of drainage for the years 1911 and 1912, and for eleven months of 1913, is given, also the rainfall for the same period. There is a very considerable range of percolation, varying in the untilled and unplanted soil from 10.5 per cent to 41.8 per cent of the rainfall, which for the period mentioned averaged 33.45 inches annually. The percolation from the four clay soils was double that from the four sandy and sandy loam soils.

This is not an exhaustive review of experiments on this subject, but it doubtless summarizes most of the investigations dealing with this phase of lysimeter experimentation. The attempt has been made to obtain, so far as possible, the results from lysimeters having a considerable depth and volume of soil, also of those experiments extending over a considerable period of time. It is questionable whether very shallow lysimeters give reliable results so far as the quantity of percolation is concerned, but the 20-inch gauge at Rothamsted shows almost exactly the same percolation during a period of thirty-five years as does the 60-inch gauge. On the other hand, at Cawnpore, India, the 3-foot gauge gave a larger drainage than did the 6-foot gauge, indicating that in a region of great evaporation there is a greater return of moisture to the atmosphere from the deeper soil, due probably to upward capillary movement during dry periods.

Another factor that is presumably of importance is the duration of the experiment, especially when the lysimeters cannot be weighed and consequently when it cannot be known whether the soil-moisture content is the same at the beginning and at the end of the experiment. Under such circumstances it is safer to continue the experiment for a number of years before calculating the percolation.

In order that the results of the experiments conducted since those reviewed by Wollny may be brought together, they are presented in table 8 arranged in the manner followed by him:

TABLE 8. RESULTS OF EXPERIMENTS IN THE PERCOLATION OF RAINFALL THRU SOIL SINCE WOLLNY'S SUMMARY

Observer	Place	Kind of soil	Crop	Depth of soil (centimeters)	Rainfall (millimeters)	Drainage (per cent of rainfall)
Ebermayer	Munich, Germany	Gravelly sand	None	120.0	131.6	85.0
Ebermayer	Munich, Germany	Fine sand	None	120.0	131.6	107.0
Ebermayer	Munich, Germany	Loam	None	120.0	131.6	94.0
Ebermayer	Munich, Germany	Limestone sand	None	120.0	131.6	43.0
Ebermayer	Munich, Germany	Muck	None	120.0	131.6	39.0
Dehérain	Grignon, France	Not known	Rotation	100.0	584.0	23.2
Creydt, Von Seelhorst, and Wilms	Göttingen, Germany	Loam	Rotation	125.0	550.0	87.6
Von Seelhorst	Göttingen, Germany	Loam	None	125.0	763.3	51.5
Von Seelhorst	Göttingen, Germany	Sand	None	125.0	763.3	57.1
Gerlach	Bromberg, Germany	Muck	Rotation	120.0	538.4	9.7
Gerlach	Bromberg, Germany	Loamy sand	Rotation	120.0	538.4	21.1
Gerlach	Bromberg, Germany	Sandy loam	Rotation	120.0	538.4	27.0
Gerlach	Bromberg, Germany	Loamy sand	Rotation	120.0	538.4	7.1
Gerlach	Bromberg, Germany	Sandy loam	Rotation	120.0	538.4	11.6
Krüger	Bromberg, Germany	Not known	None	120.0	?	55.0
Krüger	Bromberg, Germany	Not known	Rye	120.0	?	20–25
Von Feilitzen, Lugner, and Hjerstedt	Jönköping, Sweden	Muck	None	50.0	?	63.0
Von Feilitzen, Lugner, and Hjerstedt	Jönköping, Sweden	Muck	Rotation	50.0	?	35.0
Hayman and Burt	Cawnpore, India	Not known	None	182.9	1,249.7	44.3
Burt and Leather	Cawnpore, India	Not known	None	182.9	800.9	44.5
Burt and Leather	Cawnpore, India	Not known	None	91.5	800.9	48.9
Miller	Rothamsted, England	Clay loam	None	152.4	735.8	47.1
Miller	Rothamsted, England	Clay loam	None	101.6	735.8	50.4
Miller	Rothamsted, England	Clay loam	None	50.8	735.8	47.8
Fraps	College Station, Texas	Sand	None	61.0	849.6	10.5
Fraps	College Station, Texas	Clay	None	61.0	849.6	41.8
Lyon and Bizzell	Ithaca, New York	Clay loam	None	121.9	790.9	78.3
Lyon and Bizzell	Ithaca, New York	Clay loam	Rotation	121.9	790.9	54.5

These results show great differences, for which it is difficult to account. The lowest and the highest percentage percolation for bare soil are 10.5 and 107, respectively. The lowest percolation was in a region of good rainfall but great evaporation. The highest was with a light rainfall and probably what would be a moderate rate of evaporation; this was one of Ebermayer's experiments, and as the percolation in this case was greater than the rainfall the result is of doubtful accuracy.

It is noticeable that one of the experiments giving the highest percentage percolation was conducted with tile drains over a large area.

The percolation thru bare soil in the lysimeters at Göttingen agree very closely with those at Rothamsted, the rainfall being about the same at the two places. The summers are probably a little warmer at Göttingen, the winters a little colder, and the atmospheric humidity somewhat less at all times. These differences, however, are not great as compared with some of the other climates represented by the experiments.

At Cawnpore, India, the percentage percolation is less than at the two places just mentioned, and this is to be expected in a hot climate such as that of India, even tho the rainfall is greater.

The same is the case to a greater extent at College Station, Texas, where the rainfall is slightly greater than at Cawnpore, but the rate of evaporation is probably greater.

At Jönköping, with its shorter summer and consequently decreased annual evaporation, the percolation is greater than at Rothamsted. At Ithaca the percolation is even greater than at Jönköping, altho the annual evaporation is probably greater. There are other factors that may contribute to this. At Ithaca there are several months each year when the ground is frozen and when evaporation is nil. In the spring comes a thaw, which begins at the bottom of the frozen soil and gradually approaches the surface, during which time drainage takes place freely. The process of thawing causes the soil to become friable and this still further aids the drainage process. The result is that a very large proportion of the drainage occurs between the first of January and the end of April, while at Rothamsted the greatest drainage appears to occur in the autumn due to the fact that there is little freezing of the soil to facilitate the rapid carrying-off of the excess water in the early spring before conditions are favorable for evaporation.

An adequate discussion of the results of these experiments would require an accurate knowledge of the meteorological data for the place and duration of each experiment. This is in most cases difficult to obtain at this late date, but if such data had been published in connection with the reports cited above these might have made possible a more satisfactory interpretation of the experimental data. For that reason there are published in the appendix of this paper such meteorological observations as are available for the period included by the investigation (tables 4–6, pages 96–99).

Relation of flow to precipitation and season

In figures 4 and 5 are shown the monthly drainage flow from tanks 4 and 8, respectively, and the rainfall per month, calculated in liters per tank. As these two tanks have always been kept free of vegetation, they afford a means of studying the relation of flow to precipitation and to season. The graphs for rainfall begin with January, 1910, and record the total precipitation for each month up to and including April, 1915. The drainage begins with May, 1910, and extends to the same date as does the precipitation.

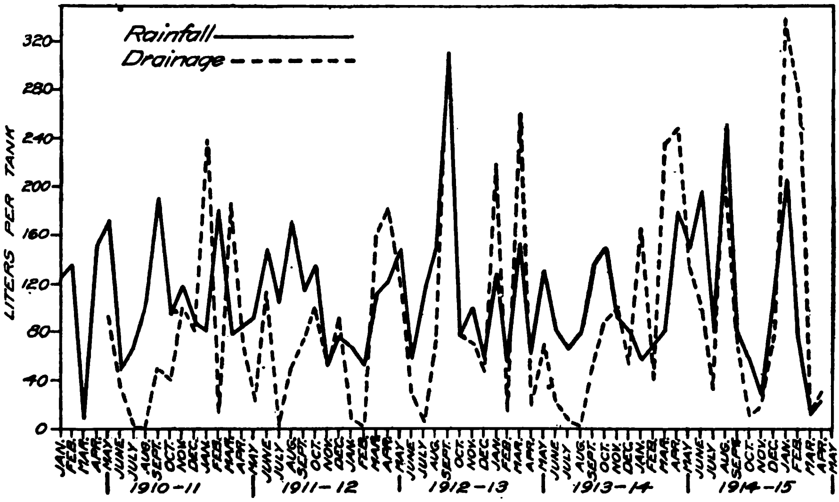


FIG. 4. RELATION OF DRAINAGE TO RAINFALL BY MONTHS FOR THE UNPLANTED TANK 4

The line for precipitation is usually higher than that for drainage. It will be remembered that about three-fourths of the rainfall for the five years passed thru the unplanted soil. Occasionally the drainage exceeds the precipitation. This occurs, with one exception only (in November, 1913), in the period included in that part of the year beginning with December and ending with April. In 1912 there was a very heavy flow in September, but it did not exceed the rainfall, which was excessive for that month and also was large for the two preceding months. Ordinarily a large flow takes place in December or January accompanying a temporary thawing of the frozen soil. February is likely to see a small amount of drainage, the soil being deeply frozen at that time. This is usually followed by the largest flow of the year in March or April, at which time the melted snow comes thru the soil.

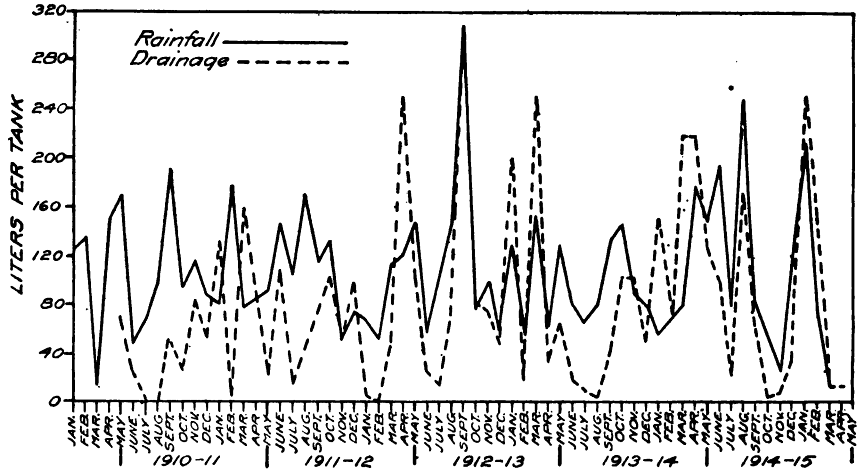


Fig. 5. RELATION OF DRAINAGE TO RAINFALL BY MONTHS FOR THE UNPLANTED AND LIMED TANK 8

Months of large rainfall are not always months of large drainage flow. This may be accounted for in the summer, when the temperatures are high and the humidity is low, by supposing a large evaporation from the surface of the soil. There appears, however, to be an accumulation of moisture in the soil for a considerable period and then a rapid discharge. In winter this is likely to be coincident with a thaw, and is then more pronounced than at other times. The heavy discharges in December, frequently exceeding the rainfall, are not usually due to an accumulation of snow but rather to an accumulation of moisture in the soil itself. Whether this occurs under natural field conditions or only in such well-drained soil as that contained in the lysimeters is not apparent from the data of these experiments.

Effect of applications of lime on percolation

Since in some of the tanks the soil was limed and in others it was not limed, an opportunity is afforded to observe the effect of the applications of lime on the amount of drainage. Tanks 7, 8, 9, 10, and 12 were limed in the spring of 1910 with burnt lime at the rate of 3000 pounds per acre. During the subsequent years this lime has had an opportunity to be worked thru the upper six or seven inches of soil. Probably it has not penetrated much deeper. It is questionable whether any flocculating action which the lime may have had on this superficial layer of soil would increase the amount of percolation. Comparisons would best be made between limed and unlimed tanks that have otherwise received similar treatments, and this is done in table 9:

TABLE 9. AVERAGE ANNUAL PERCOLATION OF RAINFALL THRU LIMED AND UNLIMED SOIL DURING FIVE-YEARS PERIOD

Crop treatment	Fertilization	Soil not limed		Soil limed	
		Tank	Flow (acre inches)	Tank	Flow (acre inches)
In rotation without clover	Farm manure	3	18.82	7	15.30
No plants allowed to grow	Farm manure	4	25.83	8	22.98
In rotation with clover	Farm manure	5	14.17	9	16.71
Oats, mixed grasses	Farm manure	6	19.73	10	14.87
In rotation without clover	Farm manure and K_2SO_4	11	18.80	12	17.25
		Average	19.47	Average	17.42

It is evident from table 9 that the application of lime has not caused a greater percolation of water. Neither can it be concluded that the opposite has been the result, for, while most of the unlimed tanks gave a larger flow of drainage, one of them gave less than the corresponding limed tank. Failure of the limed soil to give a larger percolation cannot be due to larger crops, as the yields of dry matter were somewhat larger on the unlimed tanks, besides which tanks 4 and 8 were continually bare of vegetation.

WATER UTILIZATION BY CROPS

The effect of the growth of plants was to reduce considerably the percolation from the soil on which they grew, as was to be expected. The difference in percolation between the planted and the unplanted tanks in these experiments, which as shown in table 6 (page 16) was nearly 7½ inches, probably does not represent the entire transpiration of the plants that grew on the soil, because without doubt there was more evaporation from the bare soil than from the soil on which plants grew, owing to the protection from sun and wind afforded to the soil by the vegetation itself. On the other hand, the transpiration was not less than 7½ inches as an annual average for the production of these crops, all of which, with the possible exception of that raised in 1912, were large, as may be seen in table 1 of the appendix (page 92).

While the data at hand do not admit of the calculation of the actual transpiration ratio for the crops and the period concerned, they permit of an estimation of the minimum quantity of water transpired per pound of plant dry matter produced. This is obtained by subtracting the drainage of the planted tanks from the drainage of the unplanted tanks, and amounts to 290 pounds of water to every pound of dry matter in the crop produced, or a ratio of 1:290. This appears in tabular form in table 10:

TABLE 10. MINIMUM TRANSPIRATION FOR ALL CROPS RAISED DURING FIVE-YEARS PERIOD

Tanks	Average annual percolation per tank (pounds)	Average annual production of dry matter (pounds)
4, 8	11,048	
3, 5, 6, 7, 9, 10, 11, 12	7,676	11.64
Minimum transpiration	3,372	
Minimum transpiration ratio	1:290	

The combined transpiration and evaporation from the planted tanks may be estimated by subtracting the average annual percolation for all the planted tanks from the average annual rainfall. This has been termed the evapo-transpiration of the crops, and from this may be calculated the evapo-transpiration ratio, as appears in table 11:

TABLE 11. EVAPO-TRANSPIRATION FOR ALL CROPS RAISED DURING FIVE-YEARS PERIOD

	Liters per tank
Rainfall	1,311.6
Percolation from planted tanks	697.8
Transpiration and evaporation from planted tanks	613.8
Evapo-transpiration ratio	1:580

The actual transpiration ratio for all the crops raised during the five-years period was therefore somewhere between 1:290 and 1:580. The crops raised were maize, oats, wheat, timothy, clover, and mixed grasses.

In table 12 is given a statement of the minimum transpiration ratio and the evapo-transpiration ratio for each crop raised during each year, with the exception of the wheat in 1912, which cannot be used for this

TABLE 12. MOISTURE RELATIONS OF THE CROPS ON TANKS 3 TO 12 DURING THE PERIOD FROM 1910 TO 1914

Year	Tanks	Crop	Minimum transpiration ratio	Evapo-transpiration ratio	Transpiration and evaporation (acre inches)	Dry matter in crops (pounds per acre)	Rainfall in percolate (per cent)
1910	3, 5, 7, 9, 11, 12	Maize	1:112	1:318	18.78	13,393	40.41
1910	6, 10	Oats	1:189	1:646	17.14	6,008	45.62
1911	3, 5, 7, 9, 11, 12	Oats	1:211	1:720	14.33	4,519	52.72
1911	6, 10	Mixed grasses	1:565	1:1415	16.88	2,701	44.30
1912	6, 10	Mixed grasses	1:664	1:1068	12.10	2,535	64.50
1913	3, 7, 11, 12	Timothy	1:333	1:479	10.71	5,071	63.02
1913	5, 9	Timothy and clover	1:363	1:477	13.54	6,393	53.24
1913	6, 10	Mixed grasses	1:266	1:428	8.61	4,519	70.27
1914	3, 7, 11, 12	Timothy	1:398	1:536	13.66	5,787	55.67
1914	5, 9	Timothy and clover	1:397	1:509	15.98	7,110	48.13
1914	6, 10	Mixed grasses	1:408	1:539	14.49	6,063	52.97

purpose because of the large proportion of plants that were winterkilled. The table contains also a statement of the quantity of water that passed into the air by transpiration and evaporation (this being the difference between rainfall and percolation expressed in acre inches), a record of the dry matter contained in each crop expressed in pounds per acre, and the percentage of the annual rainfall that percolated thru the soil. The annual rainfall as here given dates from May 1 of each year, which is about the time when crops are planted and growth of perennials begins. The period between harvest and the following May gives an opportunity for the moisture to readjust itself in the soil, and thus the next crop starts off with about the same moisture content (which is the capillary water capacity of the soil) as did its predecessor.

The minimum transpiration ratios shown in table 12 should be narrower than the transpiration ratios obtained by carefully controlled experi-

TABLE 13. UNIT WATER REQUIREMENTS OF PLANTS AS DETERMINED BY VARIOUS INVESTIGATORS

Crop	Lawes, Harpenden, England, 1850*	Wollny, Munich, Germany, 1876†	Hellriegel, Dahme, Germany, 1883‡	King, Madison, Wisconsin, 1895‖	Leather, Pusa, India, 1911§	Briggs and Shantz, Akron, Colorado, 1913¶
Barley	258	774	310	464	468	534
Beans	209	....	282	....	....	736
Buckwheat	....	646	363	....	....	578
Clover	269	....	310	576	....	797
Maize	....	233	....	271	337	368
Millet	....	447	....	....	....	310
Oats	....	665	376	503	469	597
Peas	259	416	273	477	563	788
Potatoes	....	....	....	385	....	636
Rape	....	912	....	....	....	441
Rye	....	....	353	....	....	685
Wheat	247	....	338	....	544	513

* Pots holding 42 pounds of field soil were used. Evaporation from the soil was reduced to a very low degree by perforated glass covers cemented on the pots. The figures quoted are from unfertilized soil.

† Wollny grew plants in humous sand in quantities ranging from 5 to 12 kilograms. Evaporation was reduced to a very low degree by perforated covers. Actual evaporation from uncropped cans was observed.

‡ Hellriegel grew plants in 4 kilograms of clean quartz sand and supplied them with nutrient solutions. The loss by evaporation from uncropped pots was used in determining losses by transpiration. In later experiments covers were used in order to cut down evaporation.

‖ King used cans holding about 400 pounds of soil. Some of these cans were set down into the earth, while others were not. Part of the work was carried on in the field; the remainder was run in vegetative houses. Normal soils were used. Evaporation from soil was very low, water being added from beneath. The data quoted are the average of a large number of tests.

§ Jars containing from 12 to 48 kilograms of soil were used. Loss by evaporation was determined on bare pots. The plants were grown in culture houses or in screened inclosures.

¶ Plants were grown in cans holding 250 pounds of soil. Evaporation from the soil was prevented by means of a paraffin covering. Work was conducted in screened inclosures. The data are the average for several years.

ments, and the evapo-transpiration ratios should be wider. In order to institute a comparison between the figures obtained in the present experiments and those obtained under controlled conditions, the unit water requirements found by a number of investigators are given in table 13.

Comparison of the figures in tables 12 and 13 shows that both maize and oats had wider ratios in all the experiments quoted than in the minimum requirements as found by the writers, and that clover also had a wider ratio than was found to be the case here.

Other experiments on water utilization by plants in lysimeters

Not many data are available on water utilization by plants raised in lysimeters. Gerlach (1912) reports that in experiments with ten lysimeters, each containing 4 cubic meters of soil and in which there were five soil types, the utilization of water, including evaporation, for six crops averaged from 500 to 700 grams for one gram of dry matter produced. The crops raised were potatoes, oats, rye, oats. This agrees fairly with the average figure of 1:580 found in these experiments for the same factor. The average annual rainfall at Bromberg was 538 millimeters, as compared with 791 millimeters at Ithaca.

As the result of a previous experiment Gerlach (1911) reports the utilization of from 416 to 1149 parts of water to one part of dry matter in a rotation of potatoes, oats, rye, oats, on unfertilized soil, and from 359 to 632 parts of water to one part of dry matter in the same rotation on the same kind of soil to which a complete fertilizer had been applied.

In reporting further experiments at Bromberg, Krüger (1911) states that in the growth of rye 488 parts of water was required to produce one part of dry matter from October to June, while from April to June only 348 parts of water was required.

On the lysimeters at Jönköping it was found by Von Feilitzen, Lugner, and Hjerstedt (1912) that an unfertilized soil produced oats, potatoes, turnips, and grass with an average evapo-transpiration of 511 parts of water to one part of dry matter. On the same muck soil with complete fertilizer only 311 parts of water was required. For each crop the water requirement per part of dry matter produced was as follows: On unfertilized soil: oats, 410 parts; potatoes, 401 parts; turnips, 715 parts; grass, 518 parts. On well-fertilized soil: oats 244 parts; potatoes, 149 parts; turnips, 473 parts; grass, 379 parts. All these figures are somewhat lower than those of the present writers.

In the weighable tanks at Göttingen, rye, barley, wheat, and potatoes were raised, and the water utilization was computed by Von Seelhorst (1906 b) from the rainfall after deductions had been made for evaporation and drainage. The evaporation from the soil was estimated, since it was evident that the evaporation from a bare soil surface would not be the same as from a soil surface shaded by plants. Calculated in this way, wheat on loam soil required 333 parts of water, and rye 375 parts, for one part of dry matter in the grain, and potatoes required 278 grams of water for one part of dry matter in the tubers; on sandy soil, rye required 482 parts of water for one part of dry matter in the grain. These results are not comparable with any of the others cited, because of the method of calculation, and data for the other method of calculation are not available.

A summary of these results and of the results from the present experiments is given in table 14:

TABLE 14. Water Utilization by Plants in Lysimeters

Observer	Place	Fertilization	Parts of water to one part of dry matter			
			Rotation	Oats	Grass	Maize
Gerlach	Bromberg, Germany	None	500–700	......	......	....
Gerlach	Bromberg, Germany	None	416–1149	......	......	....
Gerlach	Bromberg, Germany	Complete	359–632	......	......	....
Von Feilitzen, Lugner, and Hjerstedt	Jönköping, Sweden	None	511	410	518	....
Von Feilitzen, Lugner, and Hjerstedt	Jönköping, Sweden	Complete	311	244	379	....
Lyon and Bizzell	Ithaca, New York	Farm manure	580	683	681	318

As in the case of transpiration, there is a tendency for water utilization also to run higher in America than in Europe. This seems inconsistent with the fact that the percentage percolation thru a bare soil was greater in the writers' experiments than in most of the European ones. The rotations in Europe did not utilize a materially larger quantity of water than did the rotation in these experiments, but the European rotations included potatoes and root crops, both of which require much water, and the writers' rotation included maize, which is economical of moisture.

It seems very likely that the conditions were less favorable for evaporation in the European experiments than in the writers', and that the reason for the greater percentage percolation in these experiments is due to the large winter percolation, as has already been explained.

SUFFICIENCY OF MOISTURE SUPPLY FOR CROP GROWTH

The thoro drainage to which soils in the lysimeter tanks are subjected, suggested the possibility that there might be a deficiency of moisture for crop growth at some time during the growing season and that a limiting factor might thus be introduced. Provision was made at the time the tanks were constructed by which the water could be held in the tanks in the spring at any desired depth, and thus a reservoir of water be held for use of the plants during the active growing season. This was not used the first year because it was desired to ascertain whether it was needed. There was no evidence that it was, nor have subsequent crops appeared to need more moisture than was available.

It is usual for water in the cropped tanks to cease percolating in midsummer, but this does not necessarily mean that the soil is too dry to furnish all the moisture that the crops need. The yield of maize was exceptionally heavy the first year the tanks were planted. The large yield was probably due in a measure to the thoro aeration which

TABLE 15. AVERAGE YIELD OF CROPS BY YEARS ON TANKS 1 TO 12, EXPRESSED IN DRY MATTER PER ACRE

Year	Crop	Grain (bushels)	Stover (tons)	Straw (tons)	Hay (tons)
1910	Maize	111.3	2.81	....	....
1910	Oats	64.1	....	1.97	....
1911	Oats	66.5	....	1.27	....
1911	Grasses	....	....	....	1.35
1912	Wheat hay	....	....	....	1.03
1912	Grasses	....	....	....	1.28
1913	Timothy	....	....	....	2.55
1913	Timothy and clover	....	....	....	3.20
1913	Grasses	....	....	....	2.27
1914	Timothy	....	....	....	2.94
1914	Timothy and clover	....	....	....	3.54
1914	Grasses	....	....	....	3.05

the soil received in being transferred to the lysimeters, altho it was not allowed to become air-dry, which always greatly increases the quantity of soluble plant nutrients in a soil. The average yields of crops on these tanks for each of the years of the experiment are given in table 15. The yield for each tank is given in table 1 of the appendix (page 92).

If moisture were a limiting factor in the production of these crops, it may be assumed that the fact would be indicated by a diminished flow of drainage water from the tanks producing the largest crops. This could be shown by a line plotting the yields and one plotting the flow of drainage water, in which the greatest yields should correspond to the least drainage. In figure 6 are shown the yields of dry matter in the maize crops on tanks 3, 5, 7, 9, 11, and 12 in 1910, and also the quantities of drainage water in liters from the same tanks for the period beginning May 1, 1910, and ending April 30, 1911, when the moisture content of each tank would have returned to its capillary capacity. In figure 7 are shown the total yields of dry matter in the five crops raised on each of tanks 3, 5, 7, 9, 11, and 12, and also the quantities of drainage

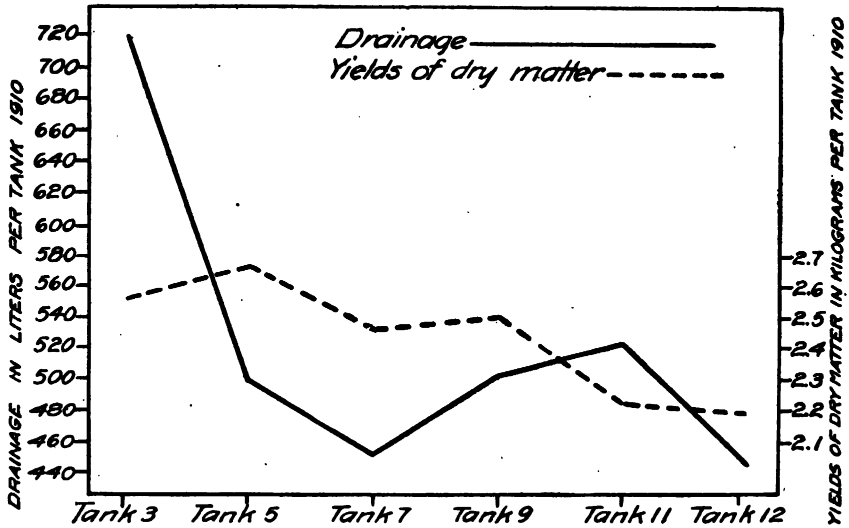


FIG. 6. TOTAL FLOW OF DRAINAGE WATER FROM CERTAIN TANKS FOR THE YEAR BEGINNING MAY 1, 1910, AND YIELD OF MAIZE ON THE SAME TANKS IN 1910

The percolation bears no direct relation to the crop yield water from each of these tanks for the five-years period beginning May 1, 1910, and ending April 30, 1915.

Neither of these diagrams indicates that there is a definite relation between the yield of crop and the quantity of drainage water from any tank. Apparently the moisture supply was adequate to produce as large crops as the other factors would allow. This shows strikingly the possibilities of storing moisture in a well-drained clay loam soil, and raises the question whether, with a normal rainfall in this climate and where drainage may be obtained, moisture need ever be a limiting factor in loam soils.

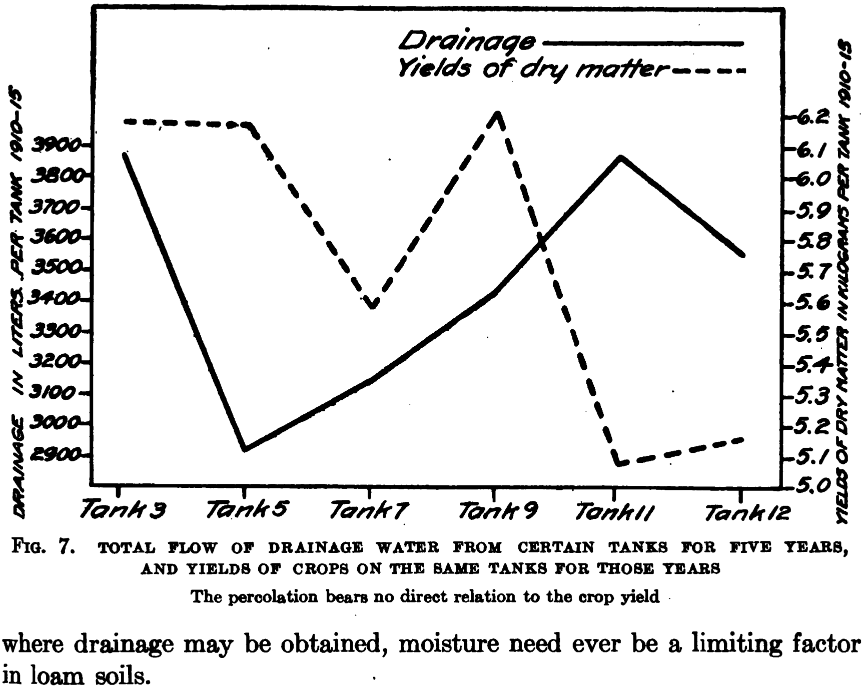


FIG. 7. TOTAL FLOW OF DRAINAGE WATER FROM CERTAIN TANKS FOR FIVE YEARS, AND YIELDS OF CROPS ON THE SAME TANKS FOR THOSE YEARS

The percolation bears no direct relation to the crop yield

A comparison of the yields of crops on the tanks in 1910, and for the same year on the corresponding field plats — which latter had no artificial drainage but received the same fertilization and produced the same kind of crops as the tanks — shows a much larger yield from the tanks. To what extent this is due to the thoro aeration to which the tank soils are subject, and how much is due to the moisture supply, it is impossible to say. The comparison is recorded in table 16:

TABLE 16. YIELDS OF CROPS IN 1910 ON TANKS AND ON SIMILARLY TREATED BUT UNDRAINED FIELD PLATS

Crop and treatment	Tank	Yield per acre (bushels)	Field plat	Yield per acre (bushels)
Maize	3	114	7002	37
Maize	5	132	7005	48
Oats	6	59	7006	37
Maize, limed	7	109	7008	44
Maize, limed	9	124	7011	51
Oats, limed	10	70	7012	50
Maize, K_2SO_4	11	96	7014	57
Maize, limed, K_2SO_4	12	109	7015	55

REMOVAL OF NITROGEN FROM THE SOIL IN DRAINAGE WATER AND IN CROPS

It is shown by table 8 of the appendix (pages 105–106) that usually, tho not always, a larger quantity of nitrates is removed in the drainage water collected between October 1 and April 30 than in that collected during the summer period. It appears to be the large flow of drainage water during the winter and early spring that causes the greater removal of nitrates at that time.

TABLE 17. NITROGEN IN DRAINAGE WATER, CALCULATED TO POUNDS PER ACRE BY YEARLY PERIODS (MAY 1 TO APRIL 30)

Tank	Crops	Fertilizer	Burnt lime (pounds)	Nitrogen in drainage water (pounds per acre)					
				1910	1911	1912	1913	1914	Total
3	Rotation without clover	Farm manure	None	11.62	7.64	14.96	2.24	0.20	36.66
4	No vegetation	Farm manure	None	126.29	80.89	153.30	83.03	70.06	513.57
5	Rotation with clover	Farm manure	None	9.79	5.29	7.28	2.37	0.93	25.66
6	Oats, grass four years	Farm manure	None	12.41	0.70	0.41	1.45	1.22	16.19
7	Rotation without clover	Farm manure	3,000	9.18	4.68	5.97	0.88	2.17	22.88
8	No vegetation	Farm manure	3,000	91.42	55.84	119.08	74.33	35.37	376.04
9	Rotation with clover	Farm manure	3,000	12.36	4.52	4.54	5.65	0.79	27.86
10	Oats, grass four years	Farm manure	3,000	12.81	1.06	0.23	1.06	0.18	15.34
11	Rotation without clover	Farm manure and K_2SO_4	None	12.36	9.09	2.60	1.51	0.93	26.49
12	Rotation without clover	Farm manure and K_2SO_4	3,000	16.61	12.09	3.75	0.43	1.13	34.01

The nitrogen in the drainage water was all in the form of nitrates, there being almost no organic matter and only traces of ammonia. The quantity of nitrogen in pounds per acre, calculated from nitrates for each of the tanks and for each year of the experiment, is given in table 17.

Relation of nitrogen removal in drainage water to total flow of drainage

In the five-years period thru which the experiments extend, great variation is shown from year to year in the quantity of nitrogen that is present in the drainage water. The range of nitrogen is greater for the tanks that had no vegetation than for those that were planted. The variations are probably controlled largely by the quantity of drainage water, rather than by weather conditions favoring a large formation of nitrates. In years of large percolation the nitrates are usually high, and in years of small percolation usually low, because a large volume of water is required in order to remove all the nitrates from the soil. The relation of the nitrogen in the drainage water to the total flow is shown in figures 8 and 9 for tanks 4 and 8, respectively.

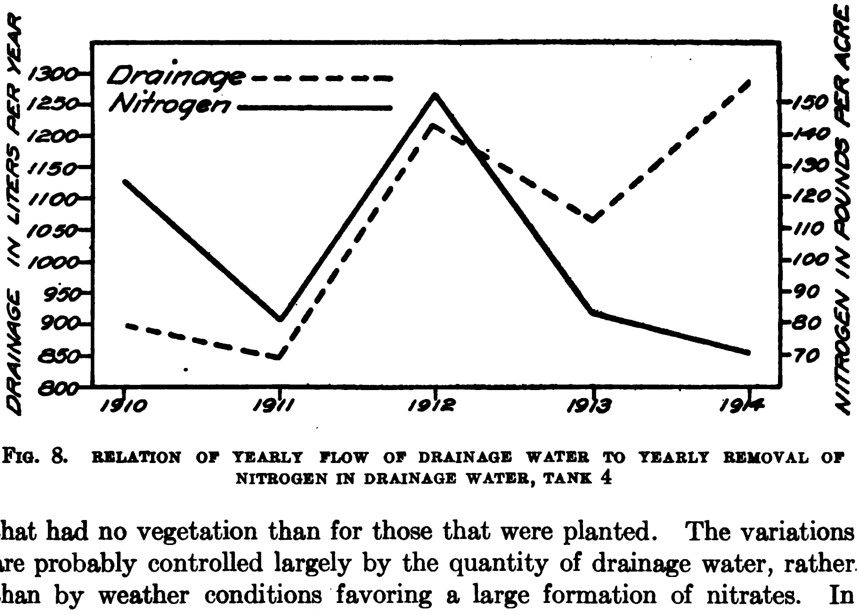


FIG. 8. RELATION OF YEARLY FLOW OF DRAINAGE WATER TO YEARLY REMOVAL OF NITROGEN IN DRAINAGE WATER, TANK 4

In 1910 the nitrogen content was high as compared with the flow of drainage water from both tanks, which may have been due either to a favorable season for nitrification or to the thoro aeration to which the soil was subjected when it was placed in the tanks in 1909. In 1914 the nitrogen showed a tendency to fall below its usual ratio to the flow of drainage water. It is difficult to trace this to any weather conditions obtaining that year, as neither the rainfall nor the temperature was abnormal during the months when nitrate formation might be expected to be active. It is possible that with the settling of the soil in the tanks and the diminished aeration, there is a tendency for the process of nitrate formation to be less active. This can be confirmed or refuted only as the experiments are continued.

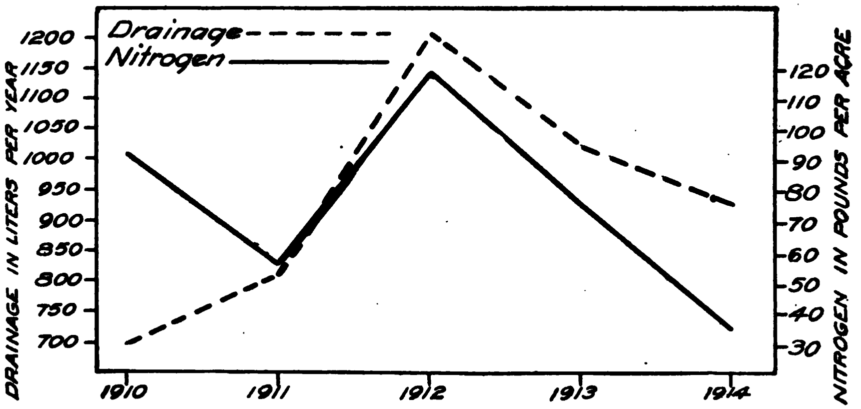


FIG. 9. RELATION OF YEARLY FLOW OF DRAINAGE WATER TO YEARLY REMOVAL OF NITROGEN IN DRAINAGE WATER, TANK 8

The most noticeable factor in determining the quantity of nitrogen in the drainage water is the presence or absence of plants on the soil. The unplanted tanks average seventeen times as much nitrogen in the yearly flow as do the planted tanks. Absorption of nitrogen by the growing plants may be assumed to account in large measure for the difference.

Effect of lime on removal of nitrogen

The application of lime apparently has not increased the amount of nitrogen in the drainage water. Comparing tanks 4 and 8, of which neither was cropped but the latter was limed, it is seen that there was more nitrogen removed from the unlimed soil during the five years than from the limed soil. A similar comparison of the planted and unlimed tanks 3, 5, 6, and 11 with the planted and limed tanks 7, 9, 10, and 12, shows that the former lost an average of 26.25 pounds of nitrogen per acre during the five years, while the latter lost 25.02 pounds. These figures for each tank and each crop are given in table 17 (page 36).

In order to ascertain whether the lime applications had any effect on the process of nitrate formation on the planted tanks, the yields and the nitrogen content of the crops on the limed tanks may be compared with those of the crops on the unlimed tanks. The yields of dry matter on the unlimed tanks 3, 5, 6, and 11 amounted to 47.34 pounds for the five-years period, while for the same period the yields of dry matter on the limed tanks 7, 9, 10, and 12 totaled 45.78 pounds. Therefore, if there is any increased nitrate formation caused by the lime applications, it is not reflected in the crop yields. On the other hand, the limed field plats duplicating the tank treatments produced a total of 928 pounds of crops during the five-years period, as compared with 851 pounds from the unlimed plats for the same period.

If the total quantity of nitrogen removed in the crops is taken as a measure of nitrate formation, there also appears to be no effect from the lime. Calculated to pounds of nitrogen per acre in crops, the limed tanks produced 1337 pounds for the five-years period and the unlimed tanks 1345 pounds. These figures are given for each tank and each crop in table 18:

TABLE 18. NITROGEN IN CROPS, CALCULATED TO POUNDS PER ACRE BY YEARLY PERIODS

Tank	Crops	Fertilizer	Burnt lime (pounds)	Nitrogen in crops (pounds per acre)					
				1910	1911	1912	1913	1914	Total
3	Rotation without clover	Farm manure	None	144.10	54.67	38.45	58.96	72.44	368.62
5	Rotation with clover	Farm manure	None	148.01	46.42	38.61	81.62	63.69	378.35
6	Oats, grass four years	Farm manure	None	88.83	29.15	23.82	54.23	86.08	282.11
7	Rotation without clover	Farm manure	3,000	151.80	51.95	41.36	40.81	53.13	342.05
9	Rotation with clover	Farm manure	3,000	152.08	52.53	31.13	82.01	67.27	385.02
10	Oats, grass four years	Farm manure	3,000	97.19	31.19	21.07	47.41	78.16	275.02
11	Rotation without clover	Farm manure and K_2SO_4	None	139.98	51.04	27.56	38.23	59.24	316.05
12	Rotation without clover	Farm manure and K_2SO_4	3,000	156.64	39.44	35.53	40.48	62.87	334.96

On the whole there appears to be no evidence that the application of lime has increased the formation of nitrates in this soil in the tanks, altho it may have done so in the corresponding plats in the field.

Effect of plant growth on nitrogen removal in drainage water

The total removal of nitrogen from the tanks used in these experiments is rather large. It is seen by tables 17 and 18 that from planted soil much more nitrogen is removed in the crops than in the drainage water. There seems to be a close margin between the quantity of nitrates produced and the quantity absorbed by the crop. When soil is cropped the loss of nitrogen in the drainage water is usually not great. On the other hand, when land is continually kept free of vegetation there is a very heavy loss of nitrogen in the drainage water, amounting usually to more than the nitrogen removed in the crop and in the drainage water combined on cropped land. This is seen by table 19, which shows that the average loss of nitrogen in the drainage water from the unplanted tanks 2, 4, and 8 averaged 460 pounds per acre for the five-years period, while the removal of nitrogen in both drainage and crops from the planted tanks 1, 3, 5, 6, 7, 9, 10, 11, and 12 averaged 362 pounds per acre.

TABLE 19. NITROGEN IN CROPS PLUS DRAINAGE WATER OF PLANTED TANKS, AND IN DRAINAGE WATER ALONE OF UNPLANTED TANKS

Tank	Crops	Fertilizer	Burnt lime (pounds)	Nitrogen in crops and in drainage water (pounds per acre)					
				1910	1911	1912	1913	1914	Total
1	Rotation without clover	Farm manure	None	127	69	56	50	68	370
2	No vegetation	Farm manure	None	141	55	101	115	79	491
3	Rotation without clover	Farm manure	None	156	62	53	61	73	405
4	No vegetation	Farm manure	None	126	81	153	83	70	513
5	Rotation with clover	Farm manure	None	158	52	46	84	65	405
6	Oats, grass four years	Farm manure	None	101	30	24	56	87	298
7	Rotation without clover	Farm manure	3,000	161	60	47	42	55	365
8	No vegetation	Farm manure	3,000	91	56	119	74	35	375
9	Rotation with clover	Farm manure	3,000	164	57	36	88	68	413
10	Oats, grass four years	Farm manure	3,000	110	32	21	48	78	289
11	Rotation without clover	Farm manure and K_2SO_4	None	152	60	30	40	60	342
12	Rotation without clover	Farm manure and K_2SO_4	3,000	173	52	39	41	64	369

RELATION OF DIFFERENT CROPS TO FORMATION OF NITRATES

The total nitrogen removal appears to vary with different crops, and it is possible that the growth of some crops would result in a larger removal of nitrogen than does the maintaining of a bare soil surface. It is obvious that the maintenance of clean cultivation, as is often practiced in orchards, is likely to lead to excessive loss of nitrogen, while the growth of a cover crop returns most of the nitrogen to the soil when the crop is plowed under.

A study of the nitrates in the drainage water and their relation to the crops produced shows the characteristic relationships that have previously been discussed by the writers (Lyon and Bizzell, 1913). This may be seen by reference to table 20, in which are stated the average quantity of nitrogen contained in each kind of crop raised — the actual quantities found being given for the tops, or aboveground parts of the plants, and an estimate of one-third that amount being assumed for the quantity contained in the roots — and also the quantity of nitrogen contained in the drainage water flowing from the tanks during the year in which the crop grew. As the nitrogen for the cropped and the uncropped soil represents the flow of drainage water for the same year, the experiment is not open to the same objection as when the flow of two or more different years is compared. While, therefore, the comparison instituted in table 20 is open to some objections — one of which is the moisture content, which is always less during the growing season

TABLE 20. AVAILABLE NITROGEN IN SOIL PRODUCING DIFFERENT CROPS, AS MEASURED BY THE NITROGEN OF THE CROP AND OF THE DRAINAGE WATER

(In pounds per acre)

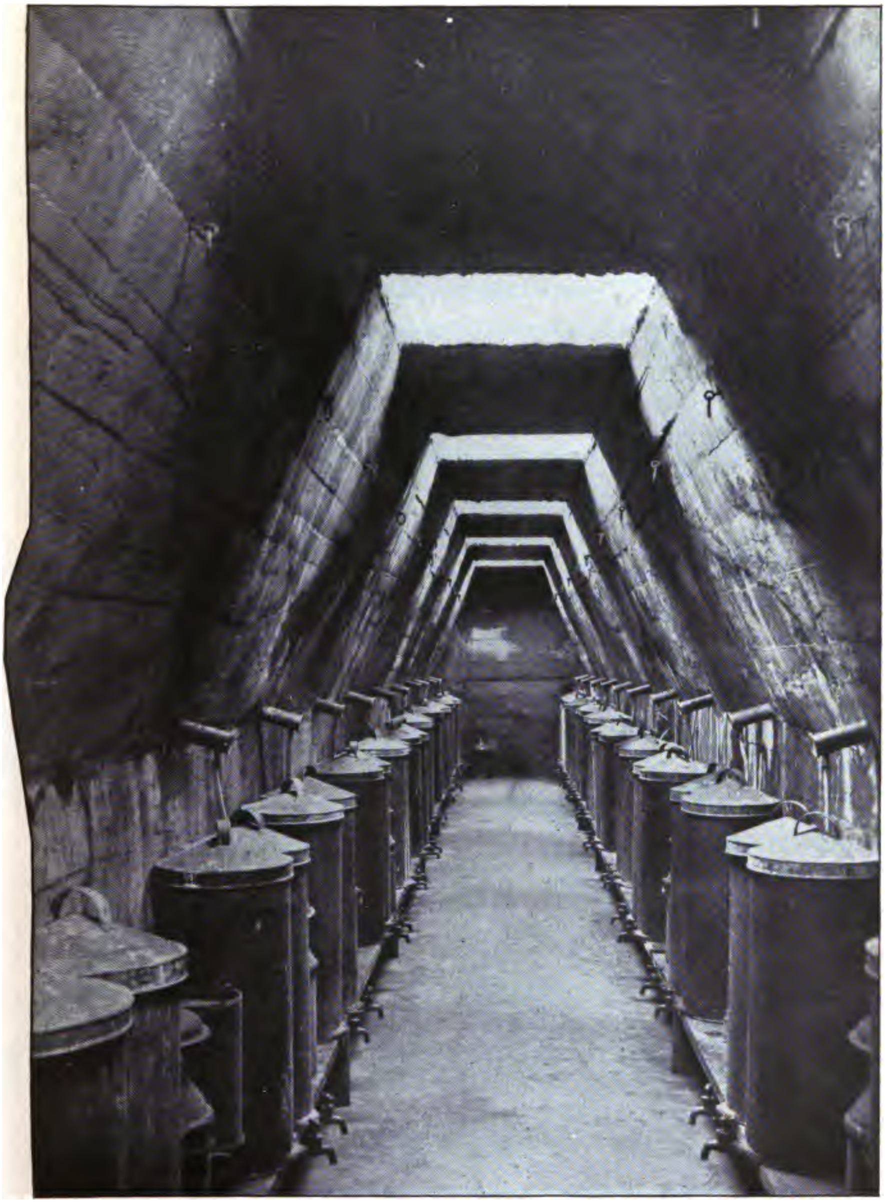
Crops	Nitrogen in planted tanks				Nitrogen in drainage water in corresponding bare tanks	Excess (+) or deficiency (—) in planted tanks
	In drainage water	In tops	In roots*	Total		
Maize	12	144	48	204	119	+ 85
Oats	9	73	24	106	92	+ 14
Mixed grasses	1	46	15	62	85	— 23
Timothy	3	49	16	68	92	— 24
Timothy and clover	2	73	24	99	76	+ 23

*Estimated at one-third the quantity in tops.

in the planted tanks than in the unplanted ones and has been discussed in the publication referred to above — the fact still remains that the comparison between different crops is all based on the same unplanted soil as a standard and such comparison is confined to the same season. There seems to be every reason, therefore, why the results of such comparison, if not quantitatively exact, should at least be qualitatively significant.

It is apparent from table 20 that there is considerable difference in the quantities of nitrogen taken up by these crops, ranging in the above-ground parts from 144 pounds per acre in maize to 46 pounds in the mixed grasses. It is to be noted also that there is more nitrogen in the drainage water from the soil on which the crops which absorbed much nitrogen grew, than in the drainage from the soil producing crops containing little nitrogen. Certain plants use a greater quantity of soil nitrogen than do others, without decreasing the quantity of nitrates in the drainage water. In this respect maize exceeds oats, and oats exceed the grasses. In the paper cited above it is suggested that some plants have the property of depressing the formation of nitrates, and that some plants possess this property to a greater degree than do others. The data here presented are in line with such an hypothesis.

The last column of table 20 shows that the tanks producing maize, oats, and clover have more nitrogen in the crop plus drainage water than is contained in the drainage water from the corresponding unplanted tanks, while the tanks in which timothy and mixed grasses were raised have less nitrogen in the crop plus drainage water than is contained in the drainage water of the corresponding unplanted tanks. If it is assumed that these plants obtained all their nitrogen from nitrates and that nitrate formation proceeded at the same rate in the planted and the unplanted soils, there would appear to be more nitrates produced in the soil of the maize, oats, and clover tanks than in the unplanted soil, indicating a stimulation of nitrate formation under these crops. To oppose this theory there is, of course, the possibility that these plants obtained part of their nitrogen in some form other than nitrates. It is known that clover takes nitrogen from the air, and it is known also that maize and oats can utilize organic nitrogen in certain forms. On the other hand, the smaller quantity of nitrogen in the crop and in the drainage water of the soil producing timothy and mixed grasses as compared with the drainage



TUNNEL BETWEEN TANKS, WITH CANS FOR COLLECTING DRAINAGE WATER AND SMALLER CANS FOR HOLDING ALIQUOT SAMPLES

water of the unplanted soil, indicates a disappearance of available nitrogen that may be accounted for by a depression of the process of nitrate formation.

There is certainly a striking difference in the quantity of available nitrogen in the soil on which these different crops have grown, and apparently this is connected with the growth of the particular kind of plant, since the other conditions were similar. While the data at hand do not supply positive evidence on the subject, they tend to confirm the hypothesis that different kinds of plants have certain characteristic relations to the process of nitrate formation.

REMOVAL OF CALCIUM

Calcium was removed in the drainage water to a greater extent than any other of the bases determined, but in the ash of the crops raised calcium was not the constituent removed in largest quantity from the soil. In table 21 is shown the average amount of calcium removed annually from the soil by drainage water and by crops during the five-years period:

TABLE 21. CALCIUM IN DRAINAGE WATER AND IN CROPS
(Pounds per acre, annual average)

Tank	Calcium in drainage water	Calcium in crops	Total calcium
3	200.7	13.0	213.7
4	370.8	....	370.8
5	104.6	16.9	121.5
6	226.0	9.8	235.8
7	167.8	12.4	180.2
8	364.0	....	364.0
9	186.6	17.6	204.2
10	154.3	9.6	163.9
11	213.1	10.2	223.3
12	199.7	11.5	211.2

Effect of plant growth on removal of calcium

The large removal of calcium in the drainage water of the unplanted soil is very noticeable in table 21. Not only is the quantity of calcium in the drainage water of the unplanted soil greater than that in the planted soil, but it is greater than the quantity contained in the drainage water and the crops combined. The average amount of calcium removed in crops and drainage water from the planted tanks, and the average amount in the drainage water of the unplanted tanks, are given in table 22:

TABLE 22. AVERAGE ANNUAL REMOVAL OF CALCIUM FROM PLANTED AND FROM UNPLANTED TANKS

(In pounds per acre)

Tanks	Soil treatment	Calcium removed in		Total calcium removed
		Drainage water	Crops	
3, 5, 6, 7, 9, 10	Planted	173.3	13.2	186.5
4, 8	Bare	367.4	....	367.4
Calcium conserved by cropping				180.9

The process of cropping conserves the calcium in the soil even when the entire crop is removed. The reason for the greater removal of calcium from the uncropped soil may be found, in part at least, in the large formation and leaching of nitrates when plants are not present. In table 23 is shown the average amount of nitrates found annually in the drainage water of the planted and the unplanted tanks:

TABLE 23. AVERAGE ANNUAL REMOVAL OF NITRATES FROM DRAINAGE WATER IN PLANTED AND IN UNPLANTED TANKS

Tanks	Soil treatment	Nitrates removed (pounds per acre)
3, 5, 6, 7, 9, 10	Planted	21.3
4, 8	Bare	393.6

The nitrates in the drainage water from the cropped soil would account for only about 8 pounds of calcium, while the nitrates from the unplanted soil correspond to about 127 pounds of calcium which might be removed in the form of nitrate. This would still leave about 178 pounds of calcium that had been removed from the planted soil in some form other than nitrate, and about 240 pounds from the unplanted soil. However, as the analyses show that there were more sulfuric acid and more silica and bicarbonates removed in the leachings of the unplanted soil than in those of the planted soil, this difference can thus be accounted for. The large removal of nitrates in the unplanted soil is undoubtedly associated with a large loss of calcium. Any management of the soil that permits the nitrates to form freely and to leach out of the soil results in a large loss of calcium, while maintaining a crop of some kind on the soil conserves the calcium. Catch crops conserve not only nitrogen but also calcium.

The concentration of calcium in the drainage water from the planted and the unplanted soil was in the same order as its total removal. This may be seen in table 24, in which is stated in parts per million the average calcium content for the five-years period:

TABLE 24. AVERAGE CALCIUM CONTENT OF DRAINAGE WATER FROM PLANTED AND FROM UNPLANTED TANKS

Tanks	Soil treatment	Calcium (parts per million)
3, 5, 6, 7, 9, 10	Planted	47.1
4, 8	Bare	69.3

The greater loss of calcium from the unplanted soil was not due entirely to the greater percolation of water thru that soil, as in that case the concentration would not be greater. Evidently the percolate from the unplanted soil has a greater solvent power for calcium.

The fact must not be lost sight of, however, that the bicarbonates were present in the drainage water of the unplanted soil, not only in larger quantity per tank, but also in slightly greater concentration than in the water from the cropped tanks. Carbonic acid also is doubtless a factor in the greater removal of calcium from the unplanted soil, but to a less extent than nitric acid. The average concentration, in parts per million, of nitrates, bicarbonates, sulfates, and silica in drainage water from the bare and the cropped tanks for the five-years period, is shown in table 25:

TABLE 25. CONCENTRATION OF SOME ACID RADICALS IN DRAINAGE WATER FROM PLANTED AND FROM UNPLANTED TANKS

(In parts per million)

Tanks	Soil treatment	Nitrates	Bicarbonates	Sulfates	Silica
3, 5, 6, 7, 9, 10	Planted	8.1	229.9	28.1	7.7
4, 8	Bare	68.5	237.3	26.5	8.5

Effect of lime on removal of calcium

Treating this soil with burnt lime at the rate of 3000 pounds per acre did not result in increasing the quantity of calcium in the drainage water or in the ash of the crops produced. A statement of the calcium removed in crops and in drainage water from the limed and the unlimed tanks is contained in table 26:

TABLE 26. AVERAGE ANNUAL REMOVAL OF CALCIUM FROM LIMED AND FROM UNLIMED TANKS

(In pounds per acre)

Soil treatment	Tanks	Calcium removed from planted tanks			Tank	Calcium leached from corresponding unplanted tanks
		In drainage water	In crops	Total		
Not limed	3, 5, 6	177.1	13.2	190.3	4	370.8
Limed	7, 9, 10	169.6	13.2	182.8	8	364.0

The application of lime was not sufficient to meet the lime requirement of the whole body of soil. If, therefore, any more calcium was dissolved from the upper soil in the limed tanks than in the unlimed, it was evidently absorbed by the still unsatisfied soil below, and the final result was about the same in both cases.

The concentration of calcium was appreciably greater in the drainage water from the limed than in that from the unlimed soil, both when planted and when kept free of vegetation, as is shown in table 27:

TABLE 27. CALCIUM IN DRAINAGE WATER FROM LIMED AND FROM UNLIMED TANKS

Tanks	Soil treatment	Calcium (parts per million)
3, 5, 6	Not limed, cropped	43.8
7, 9, 10	Limed, cropped	50.4
4	Not limed, bare	63.8
8	Limed, bare	74.9

As somewhat less water percolated thru the limed soil than thru the unlimed, it seems likely that the greater concentration of calcium in the drainage water from the limed soil was due to that cause rather than to any other.

Effect of potassium sulfate on removal of calcium

Tanks 11 and 12 were both treated with an application of 200 pounds of sulfate of potash annually, but tank 11 was not limed while tank 12 received 3000 pounds of burnt lime in the spring of 1910 and again in 1914. Since the conditions were somewhat different from those previously considered, the removal of calcium in crops and in drainage water is here tabulated (table 28):

TABLE 28. AVERAGE ANNUAL REMOVAL OF CALCIUM FROM LIMED AND FROM UNLIMED TANKS TREATED WITH SULFATE OF POTASH

(In pounds per acre)

Tank	Soil treatment	Calcium removed in		Total calcium removed
		Drainage water	Crops	
11	Not limed, K_2SO_4	213.1	10.2	223.3
12	Limed, K_2SO_4	199.7	11.5	211.2

From these tanks also there was no greater removal of calcium from the limed soil than from the unlimed.

The removal of calcium is influenced by the application of sulfate of potash fertilizer, as may be seen from table 29:

TABLE 29. AVERAGE ANNUAL REMOVAL OF CALCIUM FROM SOIL TREATED AND FROM SOIL NOT TREATED WITH SULFATE OF POTASH

(In pounds per acre)

Tanks	Soil treatment	Calcium removed in		Total calcium removed
		Drainage water	Crops	
3, 5, 6	No lime, no K_2SO_4	177.1	13.2	190.3
11	No lime, K_2SO_4	213.1	10.2	223.3
7, 9, 10	Lime, no K_2SO_4	169.6	13.2	182.8
12	Lime, K_2SO_4	199.7	11.5	211.2

It is apparent that the application of sulfate of potash resulted in an increase in the calcium, altho it did not increase the amount of potassium in the drainage water. There was an absorption of potassium by the soil and a liberation of calcium. The use of a potash fertilizer, in this form at least, should not be greater than is necessary, because not only is it an unnecessary expense, but also it causes a loss of calcium from the soil.

Percentage of calcium in plants

Altho the total removal of calcium in either the drainage water or the crops was not greater from the limed soil than from the unlimed, the percentage of calcium was, in the main, somewhat higher in the crops raised on the limed soil. This is brought out by table 30. There appears

TABLE 30. PERCENTAGE OF CALCIUM IN CROPS RAISED ON LIMED AND ON UNLIMED SOIL

Year	Unlimed soil Average of tanks 3, 5, 6		Limed soil Average of tanks 7, 9, 10	
	Grain	Straw or hay	Grain	Straw or hay
1910	0.011	0.420	0.011	0.443
1911	0.103	0.340	0.114	0.352
1912	....	0.180	....	0.250
1913	....	0.439	....	0.448
1914	....	0.204	....	0.186

to be a tendency for this peculiarity to disappear as the period after liming lengthens.

Sufficiency of the lime application

The four feet of soil in these tanks contains calcium at the rate of about 83,631 pounds per acre. The annual loss from the planted tanks, when calculated for both crops and leachings, is 194.2 pounds per acre, and from the unplanted tanks it is 367.4 pounds At this rate the annual loss amounts to 0.23 per cent of the total in the planted soil and 0.44 per cent in the unplanted soil. At the present actual loss per acre the planted soil would become exhausted of its calcium in 430 years and the unplanted in 228 years. Such a statement, however, signifies nothing, as the actual annual loss would decrease with the quantity of calcium present in the soil and thus the date of exhaustion would be delayed greatly. On the other hand, the soil would probably become unfit for ordinary farming long before the shorter of these periods had been passed.

The data obtained doubtless have some practical bearing on the quantity of lime that it will be necessary to add to such a soil in order to keep it up to its present content of calcium. This for the planted soil would amount to 271 pounds per acre annually, and for the unplanted soil 514 pounds.

It appears from the results obtained that the quantity of lime applied in 1910 was not sufficient to greatly benefit the soil. No increased yields of non-leguminous plants were obtained as the result of liming, but clover responded to the application. This indicates some benefit, altho not all that might have been expected from an adequate application. The failure of the limed soil to form more nitrates than the unlimed soil is another indication of the insufficiency of the application.

REMOVAL OF MAGNESIUM

Magnesium was found in much smaller quantity than was calcium, both in the drainage water and in the ash of the crops raised. The average amount of magnesium removed annually from the soil by drainage water and by crops during the five-years period is shown in table 31:

TABLE 31. MAGNESIUM IN DRAINAGE WATER AND IN CROPS

(Pounds per acre, annual average)

Tank	Magnesium in drainage water	Magnesium in crops	Total magnesium
3	30.2	8.3	38.5
4	60.0	....	60.0
5	28.0	8.9	36.9
6	43.1	5.1	48.2
7	40.5	8.0	48.5
8	70.4	....	70.4
9	42.9	7.8	50.7
10	37.2	4.6	41.8
11	49.2	5.8	55.0
12	47.1	6.4	53.5

Effect of plant growth on removal of magnesium

As in the case with calcium, the quantity of magnesium removed in the crop is small as compared with that lost in the drainage water, but this difference is not so marked as in the case of calcium.

Another respect in which magnesium is similar to calcium is that the quantity of magnesium in the drainage water of the unplanted soil is greater than that removed from the planted soil by the drainage water and the crops combined. This is brought out by table 32:

TABLE 32. AVERAGE ANNUAL REMOVAL OF MAGNESIUM FROM PLANTED AND FROM UNPLANTED TANKS

(In pounds per acre)

Tanks	Soil treatment	Magnesium removed in		Total magnesium removed
		Drainage water	Crops	
3, 5, 6, 7, 9, 10	Planted	37.0	7.1	44.1
4, 8	Bare	65.2	....	65.2
Magnesium conserved by cropping				21.1

The great loss of magnesium in the drainage water is apparently due in large measure to the solvent action of the nitric acid formed in and leached from that soil in large quantities.

Not only is the total removal of magnesium by the drainage water of the unplanted soil greater than that from the planted soil, but its concentration is greater in the water from the unplanted tanks, as may be seen from table 33:

TABLE 33. AVERAGE MAGNESIUM CONTENT OF DRAINAGE WATER FROM PLANTED AND FROM UNPLANTED TANKS

Tanks	Soil treatment	Magnesium (parts per million)
3, 5, 6, 7, 9, 10	Planted	10.5
4, 8	Bare	12.7

Effect of lime on removal of magnesium

While the application of burnt lime to this soil did not result in an increase in the quantity of calcium contained in the drainage water, it did increase the magnesium, as is shown in table 34:

TABLE 34. AVERAGE ANNUAL REMOVAL OF MAGNESIUM FROM LIMED AND FROM UNLIMED TANKS

(In pounds per acre)

Soil treatment	Tanks	Magnesium removed from planted tanks			Tank	Magnesium leached from corresponding unplanted tanks
		In drainage water	In crops	Total		
Not limed	3, 5, 6	33.8	7.4	41.2	4	60.0
Limed	7, 9, 10	40.2	6.8	47.0	8	70.4

There would appear to be a basic exchange resulting from the application of lime, by which magnesium was liberated and dissolved by the soil water. The crop on the limed soil, being somewhat smaller than that on the unlimed soil, utilized less of the magnesium.

The concentration of magnesium also was greater in the drainage water from the limed soil than in that from the unlimed soil, as is to be expected from the foregoing results. The data are given in table 35:

TABLE 35. MAGNESIUM IN DRAINAGE WATER FROM LIMED AND FROM UNLIMED TANKS

Tanks	Soil treatment	Magnesium (parts per million)
3, 5, 6	Not limed, cropped	9.0
7, 9, 10	Limed, cropped	12.0
4	Not limed, bare	10.9
8	Limed, bare	14.6

Effect of lime and potassium sulfate on removal of magnesium

The application of lime to the soil treated also with sulfate of potash did not increase the quantity of magnesium in the drainage water, but in the crops there was a slight increase, as shown in table 36:

TABLE 36. AVERAGE ANNUAL REMOVAL OF MAGNESIUM FROM LIMED AND FROM UNLIMED TANKS TREATED WITH SULFATE OF POTASH

(In pounds per acre)

Tank	Soil treatment	Magnesium removed in		Total magnesium removed
		Drainage water	Crops	
11	Not limed, K_2SO_4	49.2	5.8	55.0
12	Limed, K_2SO_4	47.1	6.4	53.5

The removal of magnesium in the drainage water of these tanks was very considerably greater than for those not treated with potassium sulfate, and this fact may account for the failure of the lime to still further increase the liberation of magnesium.

The effect of the sulfate of potash applications was to increase the removal of magnesium, as was the case with calcium. This is shown by table 37:

TABLE 37. AVERAGE ANNUAL REMOVAL OF MAGNESIUM FROM SOIL TREATED AND FROM SOIL NOT TREATED WITH SULFATE OF POTASH

(In pounds per acre)

Tanks	Soil treatment	Magnesium removed in		Total magnesium removed
		Drainage water	Crops	
3, 5, 6	No lime, no K_2SO_4	33.8	7.4	41.2
11	No lime, K_2SO_4	49.2	5.8	55.0
7, 9, 10	Lime, no K_2SO_4	40.2	6.8	47.0
12	Lime, K_2SO_4	47.1	6.4	53.5

There is a substitution of potassium for magnesium when the soil is treated with this fertilizer, altho quantitatively it is not so great as the substitution of potassium for calcium. Both these substitutions serve to emphasize the strong retentiveness of the soil for potassium.

Percentage of magnesium in plants

The effect of the lime application on the percentage of magnesium in the crops was not, on the whole, similar to its effect on the calcium. The effect on magnesium is shown in table 38:

TABLE 38. PERCENTAGE OF MAGNESIUM IN CROPS RAISED ON LIMED AND ON UNLIMED SOIL

Year	Unlimed soil Average of tanks 3, 5, 6		Limed soil Average of tanks 7, 9, 10	
	Grain	Straw or hay	Grain	Straw or hay
1910	0.087	0.204	0.096	0.205
1911	0.147	0.145	0.150	0.144
1912	....	0.086	....	0.111
1913	....	0.123	....	0.095
1914	....	0.088	....	0.095

There is not so much uniformity in the percentage of magnesium in these crops as is shown in the percentage of calcium, and there can hardly be said to be any relation between the application of lime and the percentage of magnesium in the crops.

CALCIUM-MAGNESIUM RATIO

In the soil that was placed in the lysimeter tanks the calcium-magnesium ratio was approximately as given in table 39:

TABLE 39. CALCIUM-MAGNESIUM RATIO IN SOIL

	First foot	Second foot	Third foot	Fourth foot
Calcium-magnesium ratio	1:1	0.6:1	0.9:1	2.5:1

The ratio of calcium to magnesium that obtains in the drainage water is very different from that in the soil. Thus, in the water that percolated thru the soil which received no fertilizer and no lime, the calcium-magnesium ratio was 5.4 to 1. This is a much wider ratio than that found in the soil itself, and in this solution the magnesium is not in sufficiently large proportion to exert any toxic action on plant growth, while in the upper three feet of soil the ratio is sufficiently narrow to menace vegetation were these ingredients equally soluble.

The effect of the lime application to this soil was to narrow the ratio in the drainage water, reducing it to 4.4:1. This is the average for the drainage from the four tanks treated similarly to the four mentioned above except for the application of lime. Instead of increasing the proportion of calcium in the drainage water, the effect of liming is to decrease it. How far this would go with greater applications of lime could not be ascertained from these experiments.

The greater solubility of calcium as compared with magnesium in soil water makes it possible to farm soil with a narrower calcium-magnesium content than would be tolerated by plants if the salts were in solution. Applications of moderate quantities of lime apparently have little effect on this ratio in ordinary soil, but if the soil contained a large excess of magnesium over calcium it is conceivable that the application of lime might, by liberating magnesium, be detrimental to crop growth.

REMOVAL OF POTASSIUM

Of the bases studied, potassium was removed in greatest quantity by the crops and, with the exception of magnesium, in least amount by the drainage water. The average amounts of potassium removed annually from the soil by drainage water during the five-years period, and by crops during the first four years of the period, are given in table 40:

TABLE 40. POTASSIUM IN DRAINAGE WATER AND IN CROPS
(Pounds per acre, annual average)

Tank	Potassium, in drainage water	Potassium in crops	Total potassium
3	52.7	90.9	143.6
4	73.3	....	73.3
5	39.7	90.5	130.2
6	46.5	58.7	105.2
7	43.7	83.5	127.2
8	48.8	....	48.8
9	45.9	91.1	137.0
10	46.8	57.8	104.6
11	43.7	77.5	121.2
12	40.3	84.0	124.3

The striking feature of these figures, as compared with those shown in the corresponding table for calcium, is the relatively small quantity of potassium in the drainage water and the large quantity in the crops.

Effect of plant growth on removal of potassium

It will be remembered that the quantity of calcium in the drainage water of the unplanted soil was greater than that in the drainage water of the planted soil plus the calcium contained in the crops. So far as potassium is concerned, the case is quite different, its total removal from the planted soil being much larger than from the unplanted soil, as is shown in table 41. Potassium differs in this respect not only from calcium but also from all the other bases, altho to a less degree. This probably explains why potassium is needed as a fertilizer for providing plant nutriment, while the other bases are not required for the same purpose. Evidently native potassium is not sufficiently soluble in the soil water to supply the needs of the crops produced, as an average of only 61 pounds of potassium was leached annually from an acre of unplanted soil to offset the 79.2 pounds removed by the average crop from the same area, while there was an average of 367.4 pounds of calcium leached from each acre of unplanted soil and only 12.6 pounds removed in the average crop. The other bases resemble calcium in having a greater removal in the drainage water from unplanted soil than in the crops raised on the planted tanks.

TABLE 41. AVERAGE ANNUAL REMOVAL OF POTASSIUM FROM PLANTED AND FROM UNPLANTED TANKS

(In pounds per acre)

Tanks	Soil treatment	Potassium removed in		Total potassium removed
		Drainage water	Crops	
3, 5, 6, 7, 9, 10	Planted	45.9	78.8	124.7
4, 8	Bare	61.0	....	61.0
Potassium conserved by not cropping				63.7

Plant growth on this soil appeared to have a depressing influence on the removal of calcium, if one is to judge from the fact that less calcium was removed from the planted soil in drainage and crop combined than from the unplanted soil in which drainage was the only means of removal. On the other hand, plant growth exerted a stimulating effect on the removal of potassium when judged by the corresponding data on that base, appearing in table 41 above. It is seen by that table that there was about twice as much potassium removed from the planted soil as from the unplanted soil, and hence it may be inferred that the removal of potassium by the crop has little or no effect on the quantity leached out by the drainage water. This apparently greater solubility of potassium in the planted soil is probably not due to the greater solvent action of the carbon dioxide excreted by plant roots, as analyses of the soil air of these tanks show that there is enough carbon dioxide in the unplanted soil as well as in the planted soil to keep the soil water saturated during the growing season.

It made little difference in the quantity of potassium removed by the drainage water whether the crops removed more or less potassium. For example, the quantity of potassium in the crops raised on tanks 6 and 10 was considerably smaller than that contained in the crops on tanks 3, 5, 7, and 9, and yet the quantity in the drainage water was not materially different, as is shown by table 42, compiled from the figures in table 40 (page 55). This is in line with the results given in the preceding table, which showed that the potassium leached from the planted soil amounted to about three-fourths of that removed from the bare soil.

TABLE 42. AVERAGE REMOVAL OF POTASSIUM IN DRAINAGE WATER FROM TANKS WITH LARGER AND WITH SMALLER QUANTITIES OF POTASSIUM IN THE CROPS

(In pounds per acre)

Tanks	Potassium in crops	Potassium in drainage water
3, 5, 7, 9	89.0	45.5
6, 10	58.2	46.6

The effect of plant growth on the concentration of potassium in the drainage water is shown in table 43:

TABLE 43. AVERAGE POTASSIUM CONTENT OF DRAINAGE WATER FROM PLANTED AND FROM UNPLANTED TANKS

Tanks	Soil treatment	Potassium water (parts per million)
3, 5, 6, 7, 9, 10	Planted	12.4
4, 8	Bare	10.1

It will be remembered that the volume of percolate from the bare soil was considerably greater than from the planted soil, which is probably, in part at least, the explanation for the more dilute condition of the water from the bare soil.

As between the drainage water from tanks containing smaller quantities of potassium in the crops and those containing larger quantities, there is no material difference in concentration, as is shown in table 44:

TABLE 44. POTASSIUM IN DRAINAGE WATER FROM TANKS WITH LARGER AND WITH SMALLER QUANTITIES OF POTASSIUM IN THE CROPS

Tanks	Potassium in crops (pounds)	Potassium in drainage water (parts per million)
3, 5, 7, 9	89.0	12.5
6, 10	58.2	12.4

It would seem that the amount of potassium in the drainage water is more or less independent of the quantity used by the crops. To what the greater solubility of potassium in the planted soil is due does not appear from these results. If the soil solution were concentrated with respect to potassium, it might be conceived that removal of potassium from solution by crop growth was soon made good by further solution of potassium from the soil, and that the soil solution would thus be kept at a uniform concentration; but the difference in the concentration of the drainage water from the planted and from the bare soil would not admit of this hypothesis.

Effect of lime on removal of potassium

The application of lime to this soil did not result in any increase in the quantity of potassium contained in the drainage water or in the amount removed by the crops. This is shown by table 45. It has been so often

TABLE 45. AVERAGE ANNUAL REMOVAL OF POTASSIUM FROM LIMED AND FROM UNLIMED TANKS

(In pounds per acre)

Soil treatment	Tanks	Potassium removed from planted tanks			Tank	Potassium leached from corresponding unplanted tanks
		In drainage water	In crops	Total		
Not limed	3, 5, 6	46.3	80.0	126.3	4	73.3
Limed	7, 9, 10	45.5	77.5	123.0	8	48.8

stated that potassium is liberated by the application of lime, that it is of interest to note any indication of such action that may be derived from the composition of the drainage water. If the application of lime to this soil liberated any potassium, it must have been absorbed by the lower layers of soil and thus did not appear in the drainage water. While there is no indication that potassium was set free by the lime treatment, it is quite probable that if this had been the case the potassium would have been absorbed by the lower soil, for the application of a potassium salt did not result in increasing the quantity of potassium in the drainage water.

The effect of the lime treatment on the concentration of potassium in solution in the drainage water, with respect both to the percolate from the planted soil and to that from the unplanted soil, is shown in table 46. It cannot be concluded from these figures that the application of lime results in increasing the concentration of potassium in the drainage water.

TABLE 46. POTASSIUM IN DRAINAGE WATER FROM LIMED AND FROM UNLIMED TANKS

Tanks	Soil treatment	Potassium (parts per million)
3, 5, 6	Not limed, cropped	12.0
7, 9, 10	Limed, cropped	12.9
4	Not limed, bare	12.2
8	Limed, bare	9.1

Altho the drainage water showed no evidence of liberation of potassium by lime, the possibility still remained that a greater removal of potassium from the limed soil by plants would prevent the appearance in the drainage water of that set free. As the potassium content of the crops raised on these tanks for four years had been determined, a comparison was made between the quantity of potassium removed by the plants that grew on the limed soils and the amount removed by the plants on the unlimed soils, and also of the percentages of potassium in the crops. The results are given in table 47:

TABLE 47. POTASSIUM IN CROPS ON LIMED AND ON UNLIMED SOIL

(Annual average of four years)

Tanks	Soil treatment	Pounds of potassium per acre	Percentage of potassium in crop	
			Grain	Straw
3, 5, 6	Not limed	80.0	0.56	2.04
7, 9, 10	Limed	77.5	0.56	2.08

The indications, on the whole, are opposed to the conclusion that potassium is liberated by the application of lime to this soil, when the quantity used corresponds roughly to the lime requirement of the surface eight inches as determined by the Veitch method.

Effect of potassium sulfate on removal of potassium

Potassium was unlike calcium and magnesium in that there was no liberation of the former produced by the application of sulfate of potash, as is evident from table 48:

TABLE 48. AVERAGE ANNUAL REMOVAL OF POTASSIUM FROM SOIL TREATED AND FROM SOIL NOT TREATED WITH SULFATE OF POTASH

(In pounds per acre)

Tanks	Soil treatment	Potassium removed in		Total potassium removed
		Drainage water	Crops	
3, 5, 6	No lime, no K_2SO_4	46.3	80.0	126.3
11	No lime, K_2SO_4	43.7	77.5	121.2
7, 9, 10	Lime, no K_2SO_4	45.5	77.5	123.0
12	Lime, K_2SO_4	40.3	84.0	124.3

There are no significant differences in the figures for the removal of potassium, either in the drainage water or in the crops, from these tanks. It may be concluded that, while the applications of sulfate of potash caused a liberation of calcium and of magnesium, the potash of this fertilizer was practically all absorbed by the soil. The rapid leaching of a potash fertilizer from a clay loam soil is not a danger.

REMOVAL OF SODIUM

Of the four bases studied, sodium was, with the exception of magnesium, removed in the least quantity in the crops produced, and, with the exception of calcium, in the greatest quantity in the drainage water. The average amounts of sodium (Na) removed annually from the soil by drainage water during the five-years period, and by crops during the first four years of the period, are given in table 49:

TABLE 49. SODIUM IN DRAINAGE WATER AND IN CROPS
(Pounds per acre, annual average)

Tank	Sodium in drainage water	Sodium in crops	Total sodium
3	99.9	9.9	109.8
4	122.4	....	122.4
5	68.0	8.3	76.3
6	82.5	10.4	92.9
7	70.2	7.5	77.7
8	82.9	....	82.9
9	78.8	7.5	86.3
10	71.3	10.8	82.1
11	84.1	6.5	90.6
12	79.8	6.3	86.1

Very little sodium is removed in the crops as compared with that leached out by the drainage water. There was not a great difference between the planted and the unplanted soils so far as the total removal is concerned.

Effect of plant growth on removal of sodium

Sodium is like calcium and magnesium, and differs from potassium, in that it is removed in greater quantity from the unplanted soil than from the planted soil. Since it is not essential to plant growth its loss is not so serious as is that of the other three bases; but the lack of it tends to bring about an acid condition of the soil. The amounts removed from planted and from unplanted soil are given in table 50:

TABLE 50. AVERAGE ANNUAL REMOVAL OF SODIUM FROM PLANTED AND FROM UNPLANTED TANKS

(In pounds per acre)

Tanks	Soil treatment	Sodium removed in		Total sodium removed
		Drainage water	Crops	
3, 5, 6, 7, 9, 10	Planted	78.4	9.1	87.5
4, 8	Bare	102.6	....	102.6
Sodium conserved by cropping				15.1

Effect of lime on removal of sodium

The application of lime to this soil depressed the loss of sodium, as is seen in table 51:

TABLE 51. AVERAGE ANNUAL REMOVAL OF SODIUM FROM LIMED AND FROM UNLIMED TANKS

(In pounds per acre)

Soil treetment	Tanks	Sodium removed from planted tanks			Tank	Sodium leached from corresponding unplanted tanks
		In drainage water	In crops	Total		
Not limed	3, 5, 6	83.5	9.5	93.0	4	122.4
Limed	7, 9, 10	73.4	8.6	82.0	8	82.9

Not only in the drainage water was there a smaller removal of sodium from the limed soil than from the unlimed, but also in the crops. Sodium resembles potassium in this respect, but its conservation was even more marked in spite of the fact that it is more soluble in the soil water than is potassium.

The concentration of sodium in the drainage water also was somewhat less for the limed soil than for the unlimed, as is shown in table 52:

TABLE 52. SODIUM IN DRAINAGE WATER FROM LIMED AND FROM UNLIMED TANKS

Tanks	Soil treatment	Sodium (parts per million)
3, 5, 6	Not limed, cropped	20.8
7, 9, 10	Limed, cropped	19.5
4	Not limed, bare	22.0
8	Limed, bare	15.1

The difference in concentration of the drainage water from the limed and the unlimed planted soil was slight, but in the drainage water from the unplanted soil there was a notably more dilute solution in the limed soil, as was also the case with potassium.

Effect of potassium sulfate on removal of sodium

The effect of the application of sulfate of potash fertilizer on the removal of sodium, as shown in table 53, was not exactly the same as that on the removal of any of the other bases:

TABLE 53. AVERAGE ANNUAL REMOVAL OF SODIUM FROM SOIL TREATED AND FROM SOIL NOT TREATED WITH SULFATE OF POTASH

(In pounds per acre)

Tanks	Soil treatment	Sodium removed in		Total sodium removed
		Drainage water	Crops	
3, 5, 6	No lime, no K_2SO_4	83.5	9.5	93.0
11	No lime, K_2SO_4	84.1	6.5	90.6
7, 9, 10	Lime, no K_2SO_4	73.4	8.6	82.0
12	Lime, K_2SO_4	79.8	6.3	86.1

The table shows that there was a slight liberation of sodium in the drainage water as the result of the fertilizer applications, but this was less than the liberation of calcium or of magnesium (tables 29 and 37). Where lime was applied, the increase of sodium. in the drainage water as the result of the fertilizer treatment was not materially greater than in the case of the unlimed soil. The crops on the potash-fertilized soil contained considerably less sodium than those on the unfertilized soil.

EFFECT OF POTASSIUM SULFATE ON TOTAL QUANTITY OF BASES IN DRAINAGE WATER

The total quantity of the four bases — calcium, magnesium, potassium, and sodium — in the drainage water from the tanks fertilized with sulfate of potash and in that from tanks not so treated, is shown in table 54:

TABLE 54. AVERAGE ANNUAL REMOVAL OF BASES IN DRAINAGE WATER AS AFFECTED BY APPLICATIONS OF SULFATE OF POTASH

(In pounds per acre)

Tanks	Soil treatment	Calcium	Magnesium	Potassium	Sodium	Total
3, 5, 6	No lime, no K_2SO_4	177.1	33.8	46.3	83.5	340.7
11	No lime, K_2SO_4	213.1	49.2	43.7	84.1	390.1
7, 9, 10	Lime, no K_2SO_4	169.6	40.2	45.5	73.4	328.7
12	Lime, K_2SO_4	199.7	47.1	40.3	79.8	366.9

The application of potassium sulfate increased in each case the quantities of calcium and magnesium, and in less degree the quantity of sodium, in the drainage water. It is doubtful whether the increase in sodium is not within the limits of experimental error. The relative increase in these constituents is shown in table 55:

TABLE 55. INCREASE OR DECREASE OF BASES IN DRAINAGE WATER, TAKING AS 100 THAT FROM SOIL RECEIVING NO SULFATE OF POTASH

Tanks	Soil treatment	Calcium	Magnesium	Potassium	Sodium	Average
3, 5, 6	No lime, no K_2SO_4	100	100	100	100	100
11	No lime, K_2SO_4	120	146	94	101	114
7, 9, 10	Lime, no K_2SO_4	100	100	100	100	100
12	Lime, K_2SO_4	118	117	89	109	112

Magnesium appears to be freely liberated from this soil both by lime and by the potassium salt, but especially by the latter. These substitutions of bases are doubtless a factor in the effects produced on the soil by fertilizers and other inorganic salts.

One marked difference between the effect of lime and that of potassium sulfate applied to this soil, is that an application of the former resulted in a decrease in the total quantity of the bases calcium, magnesium, potassium, and sodium in the drainage water, while the applications of potassium sulfate increased the total quantity of these bases. The fact that the application of potassium was combined with a strong acid (sulfuric), whereas the lime was in the form of an oxide, would probably account at least in part for this, as the quantity of sulfate was larger in the drainage water from the soil that received potassium sulfate.

OTHER EXPERIMENTS ON LOSS OF BASES

Experiments were conducted at the Jönköping Experiment Station in Sweden by Von Feilitzen, Lugner, and Hjerstedt (1912), with lysimeters having an area of 80 by 80 centimeters and a depth of 50 centimeters. All the lysimeters were filled with muck soil containing about 60 per cent of organic matter. The crops raised were oats, potatoes, and rutabagas. The average loss per year of calcium and potassium in the drainage water for four years, calculated to pounds per acre, was as follows:

Soil treatment	In rotation		In grass	
	CaO	K_2O	CaO	K_2O
Unfertilized	252	62	162	66
Acid phosphate and kainite	142	67	88	60

The percentage of the total quantity of calcium and potassium contained in the soil that was lost in the drainage water was as follows:

Soil treatment	In rotation		In grass	
	CaO	K_2O	CaO	K_2O
Unfertilized	0.019	0.005	0.010	0.005
Complete fertilizer	0.011	0.006	0.006	0.005

Von Seelhorst and Fresenius (1904) conducted experiments in the weighable lysimeters at Göttingen, Germany, which have already been described. Four tanks were used. Tanks 1, 2, and 3 were planted to oats, and tank 3 was also seeded to clover. A crop of clover was harvested in October. Tank 4 was planted to beets. All the tanks were planted in April and the drainage records were run for nearly a year from that time, so that they compare fairly well in that respect with the results recorded here. The soil was a loam. The loss of recorded bases in the drainage water for the eleven-months period, calculated to pounds per acre, was as follows:

Tank	CaO	MgO	K_2O
1	391	62	4.6
2	407	65	5.5
3	170	25	0.0
4	411	61	10.0

Hanamann (1898) reports experiments with lysimeters holding 50 kilograms of soil, of which some were planted and some were bare. The period during which drainage water was collected was only from April 1 to October 30 of one year. Obviously the annual removal of bases cannot be ascertained from this. Maize, barley, and red clover were raised in different lysimeters on the same type of soil, which was used also in a lysimeter that was kept bare. All the bases were leached in greater quantities from the bare soil than from the planted tanks.

One of the few lysimeter experiments in which lime was applied to the soil was conducted by Tacke, Immendorff, and Minssen (1898), who used small quantities of muck soil. They found that only after repeated applications of lime was the solubility of the potassium of the soil increased, but application of potassium salts increased to a marked degree the solubility of the soil calcium. Increased amounts of calcium were not found in the drainage water following the application of lime. A considerable proportion of the potassium applied in fertilizers passed thru in the drainage water.

At the Hawaiian Sugar Planters' Experiment Station, experiments with lysimeters holding 250 pounds of soil were conducted by Eckart (1903). To different tanks lime was applied in the form of (1) burnt lime, at the rate of 3.92 tons per acre, (2) ground coral, at the rate of 8.87 tons per acre, and (3) gypsum, at the rate of 11.08 tons per acre. The effect of gypsum was to increase the quantity of potash (K_2O) in the drainage water at the rate of 198 pounds per acre, but burnt lime and coral caused a loss of only 9 pounds per acre.

Lysimeters have been in use at the Bromberg Agricultural Institute since 1906. They are cylindrical in shape, and are 2 meters in diameter and 1.2 meters deep. Experiments reported by Gerlach (1910 a) cover a period from June 1, 1906, to July 29, 1909. Five soils were used in ten lysimeters, one tank of each soil being fertilized and one left unfertilized. The first year of the experiment no crops were raised; the second season all the tanks were planted to potatoes, the third season to oats, and the fourth season to rye.

The average yearly loss of calcium oxide (CaO) for the period of experimentation, including the year of fallow, varied with the different soils from 103 pounds per acre to 1803 pounds on the unfertilized soils. It may be remarked that there was less removal of both calcium and potassium in the drainage water of the fertilized soil than in the water from the unfertilized soil. The annual removal of potassium ranged from 9 pounds to 206 pounds per acre.

Another experiment with the weighable lysimeters at Göttingen is reported by Von Seelhorst and others (1913). Two tanks were used, one of which was filled with a loam soil and the other with a sandy soil. Both were kept bare of vegetation thruout one of the experiments, which continued from 1908 to 1912. The average annual removal of calcium oxide (CaO) amounted to 239 pounds per acre from the loam and 216 pounds from the sand, and of magnesium oxide (MgO) 42.5 pounds per acre from the loam and 19.2 pounds from the sand.

Experiments with lysimeters at the Florida Experiment Station are reported by Collison and Walker (1916). The tanks were 4 feet deep and had a surface area of approximately 1/2000 acre. The soil was a coarse sand, poor in plant-food materials, especially in potash. In four of the tanks peach trees were planted. Each tank was fertilized twice a year with two pounds of a mixture containing eight per cent of potash. The other fertilizer ingredients also were applied on this liberal basis. In tanks 1 and 2 the nitrogen was in the form of ammonium sulfate, in tank 3 nitrate of soda, and in tank 4 dried blood. Of the bases, definite figures are available for potash only. For the four years from 1912 to

1915 the annual loss of potash (K_2O) in drainage water was as follows: 238 pounds per acre from tank 1; 281 pounds from tank 2; 218 pounds from tank 3; and 141 pounds from tank 4. Apparently the sulfate of ammonia favored a larger removal of potash than did the nitrate of soda, and the latter in turn favored a larger removal than did dried blood. The removal of potash in the drainage water increased rapidly each year of the experiment, indicating that the soil used had very little retentivity for potassium.

Lysimeter experiments at the Hawaiian Sugar Planters' Experiment Station were conducted by Peck (1911), who used small vessels 8 inches in diameter and 2 feet in depth. Two soils were used, both of which were sandy loams. One, an upland soil, was acid to litmus; the other, from lowland, was alkaline to litmus. To one set of vessels lime was applied in the forms of oxide, carbonate, and sulfate, a sufficient quantity of each being used to supply calcium oxide (CaO) at the rate of one ton to the acre foot. The soils were kept free of vegetation. The tanks were irrigated with distilled water at intervals of two weeks, and ten irrigations were given, amounting in all to about 23 acre inches. The drainage water from these vessels contained the following quantities of lime (CaO) and potash (K_2O):

Soil treatment	Pounds per acre in drainage water	
	Lime	Potash
None	94.2	26.0
Calcium oxide	135.5	30.0
Calcium carbonate	130.5	29.3
Calcium sulfate	344.5	44.7

The effect of all the lime applications was to increase the quantity of calcium and of potassium in the drainage water. Gypsum was very active in this respect. Ammonium sulfate was applied to some vessels and this also increased the quantities of both calcium and potassium in the drainage water.

Fraps (1914) conducted experiments at the Texas Experiment Station in which he used lysimeters 12 inches in diameter and 24 inches deep. These were divided into eight sets of six vessels each, and the vessels in each set were filled with soil of a different type from those in the other sets. The soil was kept free of vegetation. The annual removal of potash (K_2O) in the drainage water varied with the type of soil, rising from a minimum of 8 pounds per acre to a maximum of 67 pounds. The lime (CaO) varied from 70 pounds to 582 pounds, and the magnesia (MgO) from 13 pounds to 53 pounds. These losses were from soils to which no fertilizer had been applied.

The experiments included the application of sulfate of potash, which was used at the average rate of about 308 pounds per acre annually. In the case of two soils this application did not increase the quantity of potassium in the drainage water, but, on the other hand, materially decreased it. There was an increase in the potassium in the drainage water of the other six soils, but the quantities varied greatly, showing, as the author remarks, large differences in the fixing power of these soils.

The potash applications increased the removal of calcium in most of the soils to a rather slight degree, but in a sandy soil potassium sulfate caused the calcium to more than double in the drainage water. In one soil the removal of calcium was depressed by the potash. Magnesia followed closely the course of lime in respect to its response to applications of potassium sulfate, but in the main the effect was less marked than with lime, and in the case of two soils the removal was decreased.

Bases in drainage water from field soils

Goessmann, Haskins, and Smith (1899) report analyses of drainage water from eleven 0.1-acre plats of land which were drained by tiles running down the middle of each plat at a depth of from 3½ to 4 feet and terminating in an open well from which the water could be drawn for analysis. No attempt was made to keep a record of the flow. On certain plats potassium was applied as muriate, and on others as potassium magnesium sulfate, together with other chemicals. The application of potassium salts was found to increase the quantity of calcium in the drainage water, and in most cases, but not in all, the muriate occasioned a greater loss of lime than did the sulfate. Magnesium also was leached in larger quantity from the plats receiving the potash salts.

Drainage water was collected from tile drains under a plat of 4.81 hectares of land, and analyses were reported, by Creydt, Von Seelhorst, and Wilms (1901). The tiles were 15 meters apart and 1.25 meters deep. The soil was a loam overlying a clay loam. Drainage was collected daily from July 28, 1899, to August 10, 1900. Analyses were made every eighth day. Beans were raised on the land in 1899 and beets in 1900. From these data the authors estimate the calcium oxide (CaO), the magnesium oxide (MgO), and the potassium oxide (K_2O) removed from one acre in the drainage water during one year to be as follows: calcium oxide (CaO), 554 pounds; magnesium oxide (MgO), 123 pounds; potassium oxide (K_2O), 7.4 pounds.

Norton (1908) made a study of the drainage basin of Richland Creek, Arkansas, covering an area of 84,954 acres of farm land that had never received fertilizers. The streams were measured every two weeks from January 6 to December 23, and samples of water for analysis were taken at the same time. From the data obtained Norton concluded that the loss from one acre of soil during the year amounted to 81 pounds of lime (CaO), 10 pounds of magnesia (MgO), 4.8 pounds of potash (K_2O), and 3 pounds of soda (Na_2O).

Gerlach (1910 b) reports experiments on eleven plats of land in Posen, where the annual rainfall was 20 inches and the percolation 20 per cent. The annual loss of lime (CaO) per acre was 190 pounds and of potash (K_2O) 5.5 pounds.

On glancing over these experiments with many different soils it is seen that the quantities of the bases vary greatly with the soils used, particularly when the soils are kept free of vegetation. With some soils the application of lime increased the removal of calcium in the drainage water, but generally it did not do so in the quantities used. Magnesium generally responded to lime applications, but there were few soils that gave any indication of a liberation of potassium by lime, except possibly in the form of gypsum.

The application of potassium salts resulted, in general, in a liberation of calcium and of magnesium. The experiments bring out strikingly the retentiveness of the soil for potassium, and the comparatively easy solubility of calcium, at least in soils heavier than sand. The Florida soil lost great quantities of potash, but it was a coarse sand and heavily manured with potash salts. In some soils the application of potassium salts did not increase the removal of potassium, while in other soils the opposite was the case.

The quantities of the bases removed in the drainage water from the soils used in these experiments are given in table 56:

TABLE 56. REMOVAL OF BASES IN DRAINAGE WATER

(In pounds per acre)

Investigators	Kind of soil	Cropped soils			
		CaO	MgO	K_2O	Na_2O
(Lysimeters)					
Von Feilitzen, Lugner, and Hjerstedt	Muck, unfertilized, in rotation	252	......	62	....
Von Feilitzen, Lugner, and Hjerstedt	Muck, unfertilized, in grass	162	......	66	....
Von Feilitzen, Lugner, and Hjerstedt	Muck, acid phosphate and kainite, in rotation	142	......	67	....
Von Feilitzen, Lugner, and Hjerstedt	Muck, acid phosphate and kainite, in grass	88	......	60	....
Von Seelhorst and Fresenius	Loam, in oats	399	63	5	....
Von Seelhorst and Fresenius	Loam, in oats followed by clover	170	25	0	....
Von Seelhorst and Fresenius	Loam, in beets	411	61	10	....
Collison and Walker	Coarse sand, with much potash and acid phosphate; one orange tree in each lysimeter:				
	Ammonium sulfate	......	......	238	....
	Ammonium sulfate	......	......	281	....
	Nitrate of soda	......	......	218	....
	Dried blood	......	......	141	....
Lyon and Bizzell	Dunkirk clay loam, farm manure	247	56	56	113
Lyon and Bizzell	Dunkirk clay loam, farm manure, lime	236	66	55	99
Lyon and Bizzell	Dunkirk clay loam, farm manure, potassium sulfate	298	80	52	114
Lyon and Bizzell	Dunkirk clay loam, farm manure, lime, potassium sulfate	277	77	48	108
(Field soils)					
Creydt, Von Seelhorst, and Wilms	Loam, complete fertilizer, in beans and beets	554	123	7	....
Norton	No fertilizer, 84,954 acres	81	10	5	3
Gerlach	Eleven different fields	190	......	5	....

Investigators	Kind of soil	Bare soil			
		CaO	MgO	K_2O	Na_2O
(Lysimeters)					
Von Seelhorst and others	Loam, unfertilized	239	42	......	....
Von Seelhorst and others	Sand, unfertilized	216	19	......	....
Fraps	Norfolk sand	70	13	10	....
Fraps	Orangeburg fine sandy loam	181	27	32	....
Fraps	Houston loam	258	47	18	....
Fraps	Houston black clay	442	40	8	....
Fraps	Yazoo clay	582	51	67	....
Fraps	Miller fine sandy loam	259	49	39	....
Fraps	Crawford clay	569	43	39	....
Fraps	Lufkin fine sandy loam	172	53	59	....
Gerlach	Loamy sand, poor in humus, fallow one year, cropped three years	103	......	9	....
Gerlach	Sandy loam, rich in humus, fallow one year, cropped three years	1,803	......	206	....
Lyon and Bizzell	Dunkirk clay loam, farm manure	519	99	88	165
Lyon and Bizzell	Dunkirk clay loam, farm manure, lime	509	115	59	112

REMOVAL OF SULFUR

Determinations have been made regularly of the sulfur in the form of sulfates in the drainage water, and of the sulfur in the crops. The average amounts of sulfur (S) removed annually from the soil by drainage water during four years, and by crops for the five-years period, are given in table 57:

TABLE 57. SULFUR IN DRAINAGE WATER AND IN CROPS

(Pounds per acre, annual average)

Tank	Sulfur in drainage water	Sulfur in crops	Total sulfur
3	31.8	11.4	43.2
4	44.0	....	44.0
5	31.5	10.5	42.0
6	43.2	9.4	52.6
7	43.9	11.0	54.9
8	53.1	....	53.1
9	41.0	9.3	50.3
10	37.7	9.2	46.9
11	56.4	8.8	65.2
12	62.0	10.0	72.0

Effect of plant growth on removal of sulfur

The removal of sulfur in the drainage water is very considerable, being from three to six times as much as the removal by the crops. The ratio varies with the soil treatment. As between the planted soil and the bare soil there is always more sulfur removed by the drainage water from the latter, but the total removal in drainage water and in crops does not differ greatly, as is seen from table 58.

There is no conservation of sulfur by cropping, as is the case with nitrogen. Apparently there is a uniform conversion of sulfur into sulfuric acid in both planted and bare soils, and this is in sufficient quantity for the needs of the plant. In fact it is probably in excess if one is to judge from the large surplus that is carried off in the drainage water. It will be remembered that the application of sulfur in the form of potassium sulfate did not result in any increase in crop yield. This, together with the liberal formation of sulfates, indicates that in this soil there is no benefit to crops to be derived from applications of sulfur. It should be noted, however, that while sulfate of potash was the only commercial fertilizer applied to any of the lysimeters, all received an application of 10 tons of farm manure at the beginning of the experiment and again in 1914. Sulfur was determined only in the manure applied in 1914. Assuming the two applications to be equal, they would contain about 62 pounds of sulfur per acre. It is quite evident that, at the rate at which sulfur is carried off by the drainage water from these tanks, there is likely to be a deficiency in the soil in a measureable length of time.

TABLE 58. AVERAGE ANNUAL REMOVAL OF SULFUR FROM PLANTED AND FROM UNPLANTED TANKS

(In pounds per acre)

Tanks	Soil treatment	Sulfur removed in		Total sulfur removed
		Drainage water	Crops	
3, 5, 6, 7, 9, 10	Planted	38.2	10.1	48.3
4, 8	Bare	48.5	....	48.5
Sulfur conserved by cropping				0.2

Effect of lime on removal of sulfur

The application of lime was accompanied by an increase in the quantity of sulfur in the drainage water, as may be seen from table 59:

TABLE 59. AVERAGE ANNUAL REMOVAL OF SULFUR FROM LIMED AND FROM UNLIMED TANKS

(In pounds per acre)

Soil treatment	Tanks	Sulfur removed from planted tanks			Tank	Sulfur leached from corresponding unplanted tanks
		In drainage water	In crops	Total		
Not limed	3, 5, 6	35.5	10.4	45.9	4	44.0
Limed	7, 9, 10	40.9	9.8	50.7	8	53.1

The larger quantity of sulfur in the drainage water of the limed soil appears to be sufficiently well marked and constant to indicate a connection between the treatment and the result, especially as the sulfur in the drainage water from tanks 11 and 12 has the same relation to the lime treatment. It seems likely that the biological process by which sulfur is oxidized in the soil is favored by the presence of a sufficient quantity of lime, just as is the process of nitrate formation.

Effect of potassium sulfate on removal of sulfur

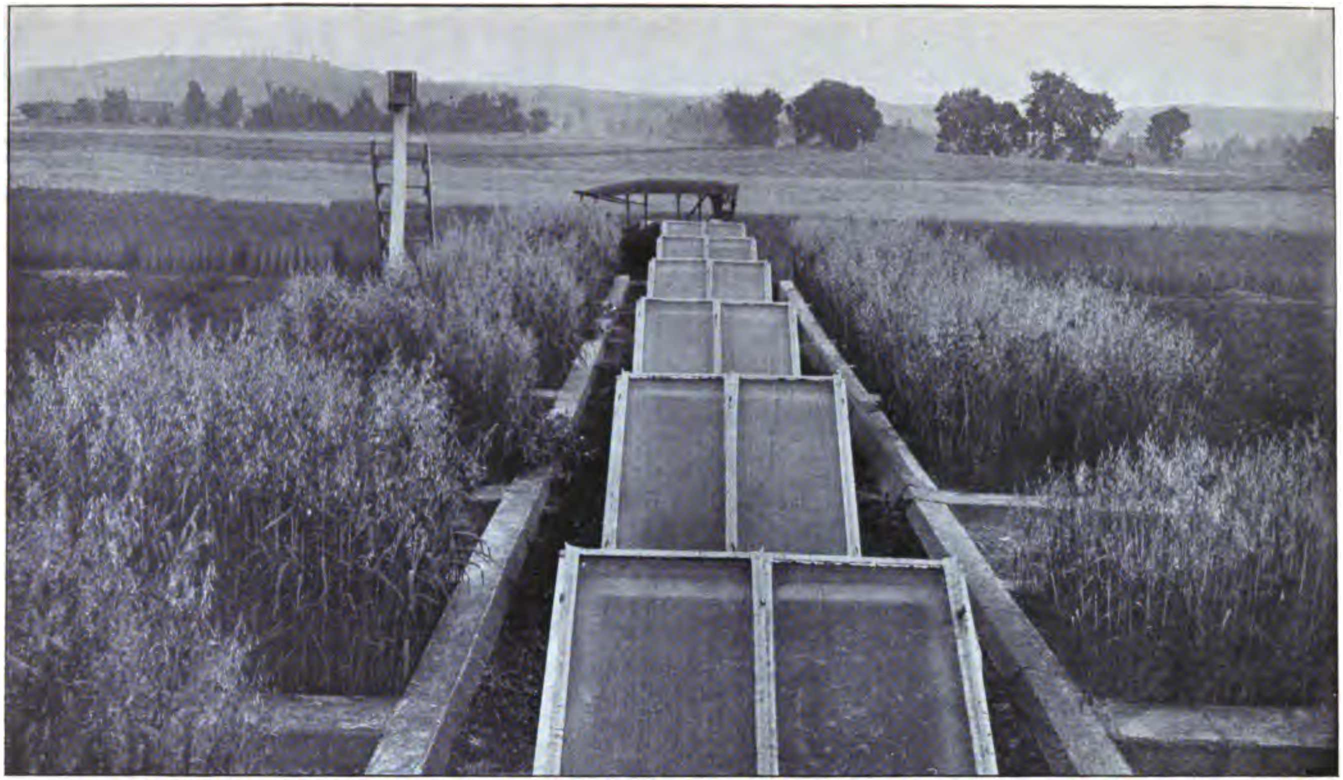
The fate of the sulfate applied to the soil is in part indicated by these experiments. Tanks 11 and 12, each of which received an annual application of 200 pounds per acre of commercial sulfate of potash, equivalent to about 35 pounds of sulfur, lost more sulfur in the drainage water than did the soil not so treated, as is shown in table 60:

TABLE 60. AVERAGE ANNUAL REMOVAL OF SULFUR FROM SOIL TREATED AND FROM SOIL NOT TREATED WITH SULFATE OF POTASH

(In pounds per acre)

Tanks	Soil treatment	Sulfur removed in		Total sulfur removed
		Drainage water	Crops	
3, 5, 6	No lime, no K_2SO_4	35.5	10.4	45.9
11	No lime, K_2SO_4	56.4	8.8	65.2
7, 9, 10	Lime, no K_2SO_4	40.9	9.8	50.7
12	Lime, K_2SO_4	62.0	10.0	72.0

The drainage water removed about 20 pounds more sulfur per acre from the soil to which sulfate of potash had been applied than from the soil not so treated, but the crop did not show increased removal. From these figures it may be inferred that over one-half of the total sulfur added in the form of sulfate was removed in the drainage water. As compared with most substances added to the soil as a fertilizer, this is a large loss. It raises the question whether the use of sulfates as a source of sulfur is economical, and whether it is not better to supply this material in the form of organic matter. It is true that sulfate is frequently present in fertilizers as an accidental constituent and adds nothing to the cost of



VIEW FROM NORTH END OF TANKS, SHOWING SKYLIGHTS IN TUNNEL AND CROP OF OATS OR OF OATS AND PEAS ON TANKS

the material. This being the case, the loss of the sulfur is not a matter of much moment, but it must be remembered that it causes also loss of lime.

Other experiments on removal of sulfur in drainage water

Not many data have been published indicating the loss of sulfur in drainage water. Hanamann (1898) reports the results of experiments with lysimeters in which several soils were placed and the drainage was collected from soil cropped and from soil uncropped. The period during which the drainage was collected was from April 1 to October 30 of one year. The quantity of sulfur in the drainage water for this period was 44 pounds per acre from a basalt soil and 37 pounds from an alluvial soil, both of which remained bare of vegetation during the entire period. In other lysimeters crops were raised on the alluvial soil. From the tank on which maize was raised there were 29 pounds of sulfur in the drainage water, and from that on which red clover grew there were 15 pounds.

In the lysimeter experiments by Von Seelhorst and Fresenius (1904), already referred to, sulfur was determined among the ingredients in the drainage water. Four lysimeter tanks were used in this experiment. Tanks 1, 2, and 3 were planted to oats; tank 3 was seeded also to clover and a crop of clover was harvested the same year. Tank 4 was planted to beets. The soil was a loam. The drainage water was collected thru a period beginning on April 1 and ending the last of the following February. The average removal of sulfur in the drainage water was as follows: 248 pounds per acre from tanks 1 and 2; 94 pounds from tank 3; 258 pounds from tank 4. The striking feature of the experiment is the small quantity of sulfur leached from the soil on which clover grew.

Gerlach (1912) reports experiments with the lysimeters at Bromberg in which a record was kept of the removal of sulfur in the drainage water. Soils from five fields were used, and one tank of each soil was fertilized and one was left unfertilized. The experiment here reported covers the thirteen months beginning on August 1, 1909, and ending on August 31, 1910. Previous to this time all the tanks had been cropped each year. For the period of this experiment the soils were all unplanted from August 1 until the next spring, when one-half the number were planted to oats and one-half were fallowed. The cropped tanks were fertilized with dipotassium phosphate and nitrate of soda. The quantities of sulfur removed in the drainage water during the thirteen months, in pounds per acre, were as follows:

Muck soil, cropped	145
Muck soil, fallowed	225
Sandy loam poor in humus, cropped	84
Sandy loam poor in humus, fallowed	108
Sand, rich in humus, cropped	58
Sand, rich in humus, fallowed	106
Sandy loam poor in humus, cropped	24
Sandy loam poor in humus, fallowed	96
Yellow sandy loam poor in humus, cropped	79
Yellow sandy loam poor in humus, fallowed	157

There is a considerable range in the sulfur removal from the soils used in Gerlach's experiments, and in some cases the quantities removed are very large while in others they are much below the average obtained in the other experiments cited. The differences in the quantities of sulfur in the drainage water from the cropped as compared with the fallow soils cannot be accounted for by the sulfur removed by the crops. It will be noticed that the fertilizer used contained no sulfur.

Experiments by Von Seelhorst and others (1913) with the weighable lysimeter tanks at Göttingen, in which a sandy soil and a loam soil were kept bare of vegetation and the drainage was collected thru a period of five years, gave a total of 40 pounds of sulfur per acre from the sandy soil and 41 pounds from the loam.

In the experiments by Creydt, Von Seelhorst, and Wilms (1901), during which drainage water was collected from an area of 4.81 hectares of land by means of tile drains 15 meters apart and laid at a depth of 1.25 meters, one of the constituents determined in the leachings was sulfur. The soil was a loam. The crops consisted of beans in 1899 and of beets in 1900. The period during which drainage was collected was from July 28, 1899, to August 10, 1900. The total quantity of sulfur leached from the soil during that time was 164 pounds per acre.

Norton (1908) likewise determined sulfur in the analyses of the drainage water from the basin of Richland Creek, Arkansas. The soil of this watershed had never received commercial fertilizers. For the period from January 6 to December 23 the quantity of sulfur carried in the drainage water was 7.1 pounds per acre.

TABLE 61. REMOVAL OF SULFUR IN DRAINAGE WATER AS FOUND BY DIFFERENT INVESTIGATORS

Investigator	Place	Kind of soil	Crop	Period	Sulfur removed during period (pounds per acre)	Annual removal of sulfur (pounds per acre)
Hanamann	Austria	Basalt	None	April 1 to October 30	44	75
Hanamann	Austria	Alluvial	None	April 1 to October 30	37	63
Hanamann	Austria	Alluvial	Maize	April 1 to October 30	29	50
Hanamann	Austria	Alluvial	Clover	April 1 to October 30	15	26
Von Seelhorst and Fresenius	Germany	Loam	Oats	April 1 to February 28	248	270
Von Seelhorst and Fresenius	Germany	Loam	Oats and clover	April 1 to February 28	94	102
Von Seelhorst and Fresenius	Germany	Loam	Beets	April 1 to February 28	258	281
Gerlach	Germany	Muck	Oats	August 1 to August 31*	145	134
Gerlach	Germany	Muck	None	August 1 to August 31	225	208
Gerlach	Germany	Sandy loam	Oats	August 1 to August 31	84	78
Gerlach	Germany	Sandy loam	None	August 1 to August 31	108	100
Gerlach	Germany	Sand	Oats	August 1 to August 31	58	54
Gerlach	Germany	Sand	None	August 1 to August 31	106	98
Gerlach	Germany	Sandy loam	Oats	August 1 to August 31	24	22
Gerlach	Germany	Sandy loam	None	August 1 to August 31	96	89
Gerlach	Germany	Sandy loam	Oats	August 1 to August 31	79	73
Gerlach	Germany	Sandy loam	None	August 1 to August 31	157	145
Von Seelhorst and others	Germany	Sand	None	Five years	40	8
Von Seelhorst and others	Germany	Loam	None	Five years	41	8
Creydt, Von Seelhorst, and Wilms	Germany	Loam	Beans and beets	July 28, 1899, to August 10, 1900	164	158
Norton	Arkansas	Mixed	Mixed	January 6 to December 23	7.1	8
Lyon and Bizzell	New York	Clay loam	Rotation	Five years	192	38
Lyon and Bizzell	New York	Clay loam	None	Five years	242	48
Lyon and Bizzell	New York	Clay loam, K_2SO_4 fertilizer	Rotation	Five years	296	59

* The experiments by Gerlach covered a period of thirteen months, from August 1, 1909, to August 31, 1910.

Hart and Peterson (1911) estimate from figures given by Hall that the annual loss of sulfur in drainage water from the Rothamsted soil is from 20 to 80 pounds per acre, depending on the fertilizer treatment.

The quantities of sulfur removed in drainage water for different periods of time, as found by a number of investigators, are given in table 61. The range of removal in these experiments is large, varying from about 8 pounds a year to about 280 pounds a year. The German experiments show the greatest losses. In most cases, cropping the soils resulted in a very considerable conservation of sulfur, amounting to more than one might expect the crops to absorb. In the writers' experiments, however, the crops used just about as much as the difference between the drainage removal from the planted and the unplanted soil. The growth of clover materially decreased the removal of sulfur in the drainage water, presumably because of the large utilization of sulfur by that crop.

REMOVAL OF PHOSPHORUS

There has never been more than a trace of phosphorus in the drainage water from any of these tanks. There are therefore no data to report on phosphorus, except as to its removal in crops. The average amount of phosphorus (P) removed annually from the soil by the crops produced is shown in table 62:

TABLE 62. PHOSPHORUS IN CROPS
(Pounds per acre, annual average)

Tank	Phosphorus in crops
3	20.6
5	21.0
6	12.8
7	20.0
9	20.8
10	12.9
11	17.0
12	19.2

The table shows that the tanks kept in grass most of the time (tanks 6 and 10) lost a much less amount of phosphorus in the crops than did the tanks on which more cereal crops were raised. The tanks on which clover was produced (tanks 5 and 9) lost more phosphorus than did the tanks otherwise similarly cropped (tanks 3, 7, 11, and 12). There appears to have been no relation between the lime applications and the quantities of phosphorus removed in the crops.

SUMMARY

The lysimeters used in these experiments consist of concrete tanks slightly over 4 feet square and of about the same depth. The bottoms are funnel-shaped, with drainpipes leading to a tunnel where the drainage water is collected. The tanks are lined with water-proofing asphaltum.

Each tank was filled with 3½ tons of clay loam soil, taken from the field in layers one foot in depth and placed in the tank in the order in which the layers occurred in the field.

The soil of some of the tanks was cropped and that of others was left bare during the five years covered in this experiment. Certain of the tanks received an application of lime at the beginning of the experiment, and some received annual applications of sulfate of potash.

All tanks received the natural rainfall but no other water. The drainage water that percolated thru the soil was collected, measured, and analyzed.

The average annual rainfall for the five years was 31.14 inches. Of the annual rainfall, 24.4 inches, or 78.35 per cent, percolated thru the unplanted soil, and 16.96 inches, or 54.46 per cent, percolated thru the cropped soil. About one-half of the rainfall passed into the air from the surface of the soil and thru the plants growing on it. In general the largest flow of drainage water was during March and April.

Applications of lime had no appreciable effect on the proportion of rainfall that percolated thru the soil.

The average evapo-transpiration ratio for the cropped soils was 1:580, the crops being maize, oats, wheat, timothy, clover, and mixed grasses. The average minimum transpiration ratio for the same crops was 1:290. The minimum transpiration ratio was least for maize and greatest for the grasses, while oats were intermediate.

With crops of large yield, amounting in the case of maize to over 100 bushels of grain, there was never a deficiency of moisture in the soil, which illustrates the great water-holding capacity of a well-drained soil.

The quantity of nitrogen in the drainage water from the unplanted soil was much greater than in the water from the cropped soil, there being seventeen times as much in the former as in the latter. The application of lime had no effect on the amount of nitrogen contained in the drainage water, neither did it affect the quantity in the non-leguminous crops. There was more nitrogen in the drainage water of the unplanted tanks than in both the drainage water and the crops of the planted tanks. Some plants used a greater quantity of soil nitrogen than did others, without causing the nitrates in the drainage water to become less. The data appear to support the idea that certain kinds of plants have a depressing influence on the production of nitrates in soil.

The quantity of calcium in the drainage water of the unplanted soil was greater than that in the crops and the drainage water combined on the planted tanks. Because of this, a conservation of 181 pounds of calcium per acre was effected by cropping the soil instead of leaving it bare.

The larger removal of calcium in the drainage water from unplanted soil than from cropped soil was apparently due in large measure to the much greater quantity of nitric acid leached from the unplanted soil. Carbonic acid also is a factor in the greater removal of calcium from the bare soil. Not only was the total quantity of bicarbonates greater in the drainage from the bare soil, but also the concentration of bicarbonates was greater. The large amount of carbonic acid excreted by the roots of plants was apparently of no effect in increasing the solvent action of the soil water on calcium, probably because the soil water was already saturated with carbon dioxide.

The application of lime at the rate of 3000 pounds per acre did not increase the quantity of calcium in the drainage water or in the ash of the crops produced. Altho the total removal of calcium in either the drainage water or the crops was not greater from the limed than from the unlimed soil, the percentage of calcium was, in the main, somewhat higher in the crops raised on the limed soil. Annual applications of potassium sulfate at the rate of 200 pounds per acre materially increased the quantity of calcium in the drainage water.

To keep the soil supply of calcium up to its present amount would require an annual application of 514 pounds per acre if the soil were kept bare of vegetation, or 271 pounds per acre if it were cropped.

Magnesium was found in much smaller quantity in the drainage water than was calcium. Its removal was decreased by cropping. Application of lime resulted in a liberation of magnesium, as indicated by its greater removal in the drainage water. Applications of sulfate of potash also increased the removal of magnesium in the drainage water.

The calcium-magnesium ratio was much wider in the drainage water than in the soil, owing to the greater solubility of the calcium over that of the magnesium. The application of lime, by making the magnesium more soluble, narrowed the calcium-magnesium ratio in the drainage water.

Potassium was removed in smaller quantity by the drainage water than by the crops, in which respect it differed from calcium, magnesium, and sodium. The application of lime did not result in increase in the quantity of potassium contained in the drainage water, nor in any increase in the amount of potassium removed by the crops. Applications of sulfate of potash did not cause increase in the removal of potassium in the drainage water.

Sodium was taken up in small amounts by crops, but was removed in larger quantity in the drainage water than was either magnesium or potassium. Application of lime decreased the removal of sodium both by crops and in the drainage water.

The removal of sulfur in the drainage water was from three to six times as great as in the crops. There was about as much carried off by the drainage water from the unplanted soil as by both drainage water and crops from the planted soil. The application of lime was accompanied by an increase in the quantity of sulfur in the drainage water. Of the sulfur added to the soil in the form of sulfate of potash, more than half was removed in the drainage.

There has never been more than a trace of phosphorus in the drainage water from any of these tanks. There appears to have been no relation between the lime applications and the quantities of phosphorus removed in the crops.

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APPENDIX

METHODS OF ANALYSIS

METHODS FOR THE CHEMICAL ANALYSIS OF SOILS

Preparation of sample.— The soil sample was prepared according to the method described in Bulletin 107 (revised) of the United States Bureau of Chemistry, page 14.

Moisture.— The moisture content was determined by the official method described in the same publication, page 14.

Total organic carbon.— The total organic carbon in the soil was determined by the optional official method described in the same bulletin, page 234.

Carbon dioxide.— The carbon dioxide was determined by the official method described on page 19 of the same bulletin.

Total phosphorus.— The total phosphorus was determined by the provisional method described on page 234 of the publication cited.

Sulfur.— In determining the sulfur content, 10 grams of the air-dried soil sample was placed in a nickel crucible and thoroly mixed with 25 grams of sodium peroxide. The mixture was heated carefully until it was completely fused, and then heated strongly for one hour. The fused mass was transferred from the crucible to a beaker by means of hot water, and the solution was slightly acidified with hydrochloric acid. The beaker was then allowed to stand on the steam bath for about five hours. The contents of the beaker were transferred to a 500-cubic-centimeter graduated flask, cooled, and made up to the mark. After thoro shaking the solution was filtered and an aliquot part of 250 cubic centimeters was treated with ammonium hydroxide to precipitate iron and aluminum. The precipitate of iron and aluminum hydroxide was filtered and thoroly washed, and the filtrate and washings were concentrated to about 200 cubic centimeters. After being slightly acidified with hydrochloric acid, this solution was heated to boiling, 10 cubic centimeters of barium chloride solution was added slowly, and the mixture was allowed to stand for twenty-four hours. The barium sulfate was filtered, washed, ignited, treated with a drop of concentrated sulfuric acid and about 1 cubic centimeter of hydrofluoric acid, and finally ignited over the blast lamp.

Calcium, magnesium, potassium, and sodium.— To determine the calcium, magnesium, potassium, and sodium content, about 10 grams of the air-dried sample was ground in an agate mortar to a practically impalpable powder. A 4-gram portion of this powder was placed in a platinum dish and saturated with dilute sulfuric acid (1:1). The excess of sulfuric acid was expelled by gentle heat over a free flame, and the mass was allowed to cool. About 5 cubic centimeters of hydrofluoric acid was added to the dish and then evaporated to apparent dryness on the water bath. The treatment with hydrofluoric acid and evaporation on the water bath was repeated three times, 1 cubic centimeter of dilute sulfuric acid being added at the final treatment. The mass was then heated gently until the excess of sulfuric acid was removed, and it was then cooled, moistened with concentrated hydrochloric acid, and allowed to stand for one hour. Water was then added and the whole was gently heated. In case an insoluble residue resulted after this treatment, the mixture was heated for some time on a water bath, and was then allowed to settle and the clear liquid was decanted. The residue was washed two or three times by decantation, and the treatment with hydrofluoric, sulfuric, and hydrochloric acids was repeated until the silica was entirely removed. The hydrochloric acid solution was then evaporated to dryness on the water bath, and the residue was saturated with dilute sulfuric acid and heated to a low red heat to remove the excess of sulfuric acid and to convert the sulfates of iron and aluminum to oxides. The residue was extracted with dilute hydrochloric acid and thoroly washed. In the filtrate were usually found small quantities of iron and aluminum. These were precipitated by the addition of ammonium hydroxide and filtered, and the precipitate was thoroly washed. The filtrate and washings were concentrated to about 75 cubic centimeters and used for the determination of calcium according to the official method described in Bulletin 107 (revised) of the United States Bureau of Chemistry, page 15. The filtrate and washings from the calcium precipitate were made up to 200 cubic centimeters, one-half of which was used for the determination of magnesium according to the official method described on page 16 of the bulletin cited above, and one-half for the determination of potassium and of sodium by the official method described on page 17 of the same publication.

Total nitrogen.— For the total nitrogen determination, usually 7 grams of the soil was placed in a Kjeldahl digestion flask, with approximately 35 cubic centimeters of concentrated sulfuric acid, 10 grams of potassium sulfate, and about 1 gram of copper sulfate. The mixture was boiled for several hours until the organic matter was completely oxidized. The distillation of the ammonia was then carried out in the usual manner as described in Bulletin 107 (revised) of the United States Bureau of Chemistry, page 6.

Lime requirement.— The Veitch method was used for the determination of lime requirement, the following procedure being adopted. To three portions of soil, each consisting of as many grams as the standard limewater contained milligrams of lime (CaO) per cubic centimeter, was added from 50 to 60 cubic centimeters of distilled water and different amounts of standard limewater as follows: to the first portion 10 cubic centimeters of limewater was added, to the second portion 20 cubic centimeters, and to the third portion 30 cubic centimeters. The evaporator containing the mixture was placed at once on the steam bath. When dry the residue was transferred to a stoppered Jena flask with 100 cubic centimeters of distilled water and allowed to stand overnight, with occasional shaking. In the morning 50 cubic centimeters was drawn off and placed in a Jena beaker, a few drops of phenolphthalein were added, and the mixture was boiled until the pink color appeared, or, in case no color developed, to a volume of about 5 cubic centimeters. Then with two portions of treated soil, of which one had been rendered alkaline by the limewater, and the other, still acid, was used as a guide, three fresh portions of 10 grams each were prepared and limewater was added as before, except that the amount added to a dish differed from that added to the others by 1 or 2 cubic centimeters. The remainder of the procedure was carried out exactly as before. The smallest quantity of limewater which gave the characteristic pink color was taken as the lime requirement of the soil.

METHOD FOR THE MECHANICAL ANALYSIS OF SOILS

The centrifugal method, described in Bulletin 84 of the United States Bureau of Soils, page 9, was used for the mechanical analysis of soils.

METHODS FOR THE CHEMICAL ANALYSIS OF CROPS

Preparation of sample.— The air-dry sample was ground to a fineness sufficient for passing thru a sieve having circular perforations 1 millimeter in diameter, and then thoroly mixed.

Moisture.— A convenient quantity of the sample (from 2 to 5 grams) was dried at the temperature of boiling water for five hours. The loss in weight was considered as moisture content

Nitrogen.— Nitrogen was determined by the official Gunning method described in Bulletin 107 (revised) of the United States Bureau of Chemistry, page 7, with the following slight modification. Approximately 1 gram of copper sulfate was added to the Kjeldahl flask at the beginning of the digestion.

Phosphorus.— The method of making the solution for determining the phosphorus content of the crops was as follows. Two grams of the sample was placed in a platinum dish and mixed with 5 cubic centimeters of magnesium nitrate solution The mixture was then dried, ignited, and dissolved in hydrochloric acid.

The determination of phosphorus was made by the optional volumetric method described in Bulletin 107 (revised) of the United States Bureau of Chemistry, page 4.

Sulfur.— The provisional peroxide method, described on page 23 of the bulletin cited above, was used for determining the sulfur content.

Ash.— To determine the ash content, 10 grams of the sample was placed in a platinum dish, and the whole was placed in a graphite muffle and heated gently until the volatile matter was expelled. The heat was then raised to just below redness and this temperature was maintained for several hours. The contents of the dish were then extracted with distilled water and the insoluble residue was dried and incinerated until it was white. The aqueous extract was then evaporated and added to the ash.

Calcium, magnesium, potassium, and sodium.— To determine the calcium, magnesium, potassium, and sodium content, the ash, prepared as described above, was transferred to a beaker or an evaporating dish and dissolved in hydrochloric acid. This was evaporated to complete dryness, to render the silica insoluble. The residue was moistened with from 5 to 10 cubic centimeters of hydrochloric acid, 50 cubic centimeters of water being added, allowed to stand on the water bath for a few minutes, and filtered. The filtrate was neutralized with ammonium hydroxide and then acidified with hydrochloric acid. Neutral ferric chloride was then added in excess and the resulting precipitate was removed by filtration. The excess of iron in the filtrate was then removed by precipitation with ammonium hydroxide solution. This procedure for the removal of phosphorus was found to be much shorter than the official method, in which sodium acetate is recommended.

The filtrate and washings from the ferric hydroxide precipitate were concentrated to about 75 cubic centimeters and used for the determination of calcium, according to the official method described in Bulletin 107 (revised) of the United States Bureau of Chemistry, page 15. The filtrate and washings from the calcium precipitate were made up to 200 cubic centimeters, one-half of which was used for the determination of magnesium according to the official method described on page 16 of the bulletin cited above, and the other half for the determination of potassium and sodium by the official method described on page 17 of the same publication.

METHODS FOR THE CHEMICAL ANALYSIS OF DRAINAGE WATER AND RAIN WATER

Total solids.— To determine the total solids in the drainage water and the rain water, 100 cubic centimeters was evaporated to dryness in a platinum dish on the water bath and the residue was dried to constant weight at the temperature of boiling water.

Ammonia.— Ammonia was determined by distilling 250 cubic centimeters of the water after it had been rendered alkaline with a saturated solution of sodium carbonate. The distillate was examined by the well-known Nessler method, described in Bulletin 31 of the United States Bureau of Soils, page 30.

Nitrates.— The nitrates were determined by the method described in Bulletin 31 of the United States Bureau of Soils, page 39.

Sulfates.— The sulfates were determined by the method described on page 49 of the bulletin cited above.

Bicarbonates.— The bicarbonates were determined by the method described on page 58 of the same publication.

Silica.— For the determination of silica, two liters of the water was acidified with nitric acid and evaporated to dryness. To the residue dilute hydrochloric acid was added and the mixture was evaporated to complete dryness. The resulting residue was taken up with hot water, and a small quantity of hydrochloric acid was filtered, washed thoroly with hot water, dried, ignited, and weighed as silica.

Phosphorus.— To determine the phosphorus content, the filtrate and washings from the silica were made up to 200 cubic centimeters, and one-half was taken for the determination of phosphorus gravimetrically according to the official method described in Bulletin 107 (revised) of the United States Bureau of Chemistry, page 3.

Calcium, magnesium, potassium, and sodium.— The remaining 100 cubic centimeters not used for the phosphorus determination was treated with ammonium hydroxide to remove iron and aluminum and the precipitate was filtered and washed thoroly. The filtrate and washings were concentrated to about 75 cubic centimeters and calcium was determined by the official method described in Bulletin 107 (revised) of the United States Bureau of Chemistry, page 15. The filtrate and washings from the calcium precipitate were made up to 200 cubic centimeters, one-half of which was used for the determination of magnesium according to the official method described on page 16 of the bulletin cited, and the other half for the determination of potassium and sodium according to the official method described on page 17 of the same publication.

METHODS FOR THE CHEMICAL ANALYSIS OF MANURE

The preparation of the sample, and the determinations of moisture, nitrogen, phosphorus, and sulfur, for the chemical analysis of manure, were made according to the methods already described for the analysis of the crop.

Potassium.— The potassium content in manure was determined by the official method for determining potassium in organic compounds, described in Bulletin 107 (revised) of the United States Bureau of Chemistry, page 11.

Calcium and magnesium.— A 5-gram sample was incinerated and dissolved in a small quantity of hydrochloric acid. The resulting solution was cooled and made up to 500 cubic centimeters, and an aliquot part corresponding to 0.5 gram of the original sample was taken for the determination of calcium and magnesium according to the official methods described in Bulletin 107 (revised) of the United States Bureau of Chemistry, pages 15 and 16.

METHODS FOR THE CHEMICAL ANALYSIS OF QUICKLIME AND LIMESTONE

Calcium and magnesium.— A 5-gram sample was dissolved in hydrochloric acid and made up to 500 cubic centimeters, and a 25-cubic-centimeter aliquot part was taken for the determination of calcium and magnesium according to the official method described in Bulletin 107 (revised) of the United States Bureau of Chemistry, pages 15 and 16.

METHODS FOR THE ANALYSIS OF POTASSIUM SULFATE

Potassium.— Determination of potassium was by the official method for the determination of potassium in potash salts, described in Bulletin 107 (revised) of the United States Bureau of Chemistry, page 11.

TABLE 1. CROP YIELDS FROM LYSIMETER TANKS 1 TO 12 DURING THE PERIOD FROM 1910 TO 1914, EXPRESSED AS DRY MATTER

Year	Tank	Crop	Per tank			Per acre		
			Grain (grams)	Cob (grams)	Hay, straw, or stover (grams)	Grain (bushels)	Cob (tons)	Hay, straw, or stover (tons)
1910.....	1	Maize..	957.74	192.60	1,072.57	93.8	0.53	2.95
	3	Maize..	1,168.74	243.00	1,151.71	114.4	0.67	3.17
	5	Maize..	1,352.07	313.20	1,001.48	132.4	0.86	2.75
	6	Oats...	342.24	......	717.49	58.7	......	1.97
	7	Maize..	1,116.62	243.00	1,103.40	109.3	0.67	3.03
	9	Maize..	1,262.80	279.00	958.80	123.6	0.77	2.64
	10	Oats...	405.65	......	716.50	69.6	......	1.97
	11	Maize..	984.16	229.50	1,012.50	96.4	0.63	2.78
	12	Maize..	1,116.22	211.40	860.48	109.3	0.58	2.37
1911.....	1	Oats...	460.5	......	573.3	79.0	......	1.58
	3	Oats...	402.0	......	459.9	69.0	......	1.27
	5	Oats...	323.3	......	390.3	55.5	......	1.07
	6	Grass..	....	......	474.5	....	......	1.30
	7	Oats...	383.9	......	451.6	65.9	......	1.24
	9	Oats...	402.7	......	458.4	69.1	......	1.26
	10	Grass..	....	......	512.0	....	......	1.41
	11	Oats...	378.3	......	403.9	64.9	......	1.11
	12	Oats...	361.5	......	486.1	62.0	......	1.34
1912.....	1	Wheat..	....	......	509.6	....	......	1.40
	3	Wheat..	....	......	343.0	....	......	0.94
	5	Wheat..	....	......	380.7	....	......	1.05
	6	Grass..	....	......	508.1	....	......	1.40
	7	Wheat..	....	......	388.1	....	......	1.07
	9	Wheat..	....	......	348.5	....	......	0.96
	10	Grass..	....	......	422.0	....	......	1.16
	11	Wheat..	....	......	334.0	....	......	0.92
	12	Wheat..	....	......	322.3	....	......	0.89
1913.....	1	Hay...	....	......	954.0	....	......	2.62
	3	Hay...	....	......	1,162.2	....	......	3.20
	5	Hay...	....	......	1,179.4	....	......	3.24
	6	Hay...	....	......	850.8	....	......	2.34
	7	Hay...	....	......	914.7	....	......	2.52
	9	Hay...	....	......	1,151.3	....	......	3.17
	10	Hay...	....	......	803.9	....	......	2.21
	11	Hay...	....	......	784.2	....	......	2.16
	12	Hay...	....	......	822.8	....	......	2.26
1914.....	1	Hay...	....	......	1,175.4	....	......	3.23
	3	Hay...	....	......	1,262.9	....	......	3.47
	5	Hay...	....	......	1,232.9	....	......	3.39
	6	Hay...	....	......	1,213.1	....	......	3.34
	7	Hay...	....	......	985.5	....	......	2.71
	9	Hay...	....	......	1,345.0	....	......	3.70
	10	Hay...	....	......	1,002.1	....	......	2.76
	11	Hay...	....	......	956.9	....	......	2.63
	12	Hay...	....	......	975.5	....	......	2.68

TABLE 2. FLOW OF DRAINAGE WATER FROM LYSIMETER TANKS 1 TO 12 FROM MAY 1, 1910, TO APRIL 30, 1915
(In liters)

Year and month	Tank											
	1	2	3	4	5	6	7	8	9	10	11	12
1910 — May	57.52	66.16	88.96	92.80	68.24	91.12	63.20	70.16	62.16	60.72	75.73	67.20
June	28.64	22.48	30.64	30.96	22.00	26.40	24.40	24.16	20.24	21.60	18.64	20.64
July	1.12	0.64	0.40	0.64	1.36	0.40	1.34	2.00	0.32	0.	1.28	1.20
August	0.	0.	0.	0.16	0.	0.40	0.	0.	0.	0.08	0.	0.
September	0.	36.40	1.20	48.00	1.20	0.	0.	51.20	0.	0.	0.	0.
October	0.16	29.20	0.40	38.00	0.	0.	0.	25.84	0.	0.	0.	0.
November	0.	87.20	0.	99.36	0.	12.00	0.	84.40	0.	0.	0.	0.
December	2.88	87.20	3.12	80.16	1.60	67.36	0.	52.00	14.72	38.00	52.00	10.40
1911 — January	94.16	229.60	320.80	237.44	150.64	186.32	103.60	131.84	132.72	112.32	128.40	111.92
February	11.20	22.40	16.80	14.40	8.00	7.20	4.80	5.20	6.40	4.80	22.40	5.20
March	128.00	124.88	180.08	185.28	167.68	212.40	164.00	157.92	178.88	132.16	152.24	156.64
April	74.64	64.80	79.28	71.60	78.48	109.68	92.08	93.36	88.00	101.12	72.64	72.24
Totals	398.32	770.96	721.68	898.80	499.20	713.28	453.42	698.08	503.44	470.80	523.33	445.44
1911 — May	14.8	24.8	23.6	21.60	25.60	29.20	24.00	22.0	32.80	14.4	29.2	28.8
June	49.2	78.0	89.0	112.96	79.84	41.52	72.52	107.6	96.88	12.8	112.4	96.4
July	0.	7.2	0.	2.00	0.	0.40	0.	14.4	0.	0.	0.	0.
August	4.4	17.6	6.4	47.20	16.80	0.	10.80	46.4	24.00	0.	44.0	12.8
September	0.	33.6	0.	74.40	4.80	11.20	2.40	70.8	8.80	0.	28.8	4.0
October	0.	69.6	32.8	97.60	18.40	65.20	18.00	101.6	45.60	0.	43.2	33.6
November	0.	42.4	38.4	52.40	30.80	43.60	34.00	50.4	41.60	3.2	36.0	32.8
December	84.0	66.4	94.4	92.00	83.20	104.80	88.00	96.8	93.60	78.4	79.2	84.8
1912 — January	4.4	4.0	7.2	7.20	10.80	5.20	3.20	4.8	7.20	7.2	0.	8.0
February	0.	0.	0.	0.	5.60	0.	20.80	0.	0.	8.0	4.0	17.6
March	60.0	118.0	186.8	158.00	233.60	136.80	198.80	48.8	136.80	206.4	174.8	187.2
April	89.2	133.2	172.8	182.40	149.60	173.60	132.00	248.8	156.00	164.0	162.8	167.2
Totals	306.0	594.8	651.4	847.76	659.04	611.52	604.52	812.4	643.28	494.4	714.4	673.2
1912 — May	65.6	90.0	72.8	114.8	54.8	102.0	76.4	100.8	83.2	70.4	99.2	76.0
June	0.4	9.2	5.2	26.8	0.	7.6	2.8	24.8	18.0	1.6	14.8	8.0
July	0.4	3.2	8.0	4.0	0.	0.	0.	12.8	0.	0.	0.	0.
August	0.8	21.6	0.	72.4	0.	1.2	0.	69.6	0.	0.	6.0	0.
September	112.4	131.6	245.6	303.2	93.6	242.4	184.8	296.0	147.2	125.6	252.0	217.2
October	46.4	40.8	73.6	76.8	48.0	56.0	61.6	80.8	48.0	38.4	63.2	51.2
November	40.8	40.8	83.2	69.6	51.2	66.4	54.4	73.6	49.6	36.0	57.6	41.6
December	45.6	29.6	54.4	45.6	41.6	56.8	45.6	48.0	51.2	46.4	44.8	36.8
1913 — January	109.2	108.0	203.2	216.0	104.8	217.2	185.2	198.4	219.2	172.0	205.6	183.6
February	15.2	8.8	18.0	12.0	18.4	14.4	18.4	16.4	21.6	16.8	18.0	16.8
March	105.2	84.8	229.6	260.2	210.4	230.4	210.8	253.6	238.4	214.4	250.4	228.8
April	29.2	20.8	31.2	18.0	18.4	57.2	26.4	32.8	42.4	36.8	34.4	27.2
Totals	571.2	589.2	1,024.8	1,219.4	641.2	1,051.6	866.4	1,207.6	918.8	758.4	1,046.0	887.2

TABLE 2 (*concluded*)

Year and month	Tank											
	1	2	3	4	5	6	7	8	9	10	11	12
1913 — May	2.8	33.2	7.2	66.0	0.	43.2	12.8	64.8	8.8	18.4	27.2	13.6
June	0.	14.4	0.	21.2	0.	4.8	0.	16.8	0.	12.8	1.6	0.4
July	0.	3.6	0.	4.0	0.	0.8	0.	10.4	0.	0.	0.8	0.4
August	0.	1.6	0.	0.	0.	0.	0.4	4.0	0.	0.	0.	0.8
September	10.0	24.8	13.2	50.4	0.	20.8	6.0	41.6	7.6	2.4	9.6	0.8
October	0.8	29.6	2.4	88.0	0.	8.8	0.	103.2	0.	0.	23.2	4.0
November	1.6	58.8	28.8	99.2	0.	88.4	46.0	101.6	20.8	60.8	86.8	88.0
December	38.4	36.8	41.6	51.6	0.	59.2	42.8	48.8	43.2	45.6	45.6	45.2
1914 — January	128.0	120.8	144.4	165.2	95.2	206.8	162.4	152.0	128.8	115.2	108.8	125.6
February	54.4	40.8	54.4	40.0	47.2	53.6	48.4	70.4	52.0	47.2	43.2	48.0
March	139.2	180.4	230.8	233.2	220.0	215.2	171.2	217.6	228.4	196.4	217.2	216.4
April	207.2	221.6	225.2	246.0	194.0	252.0	200.0	218.0	223.6	223.2	228.8	230.0
Totals	582.4	766.4	748.0	1,064.8	556.4	953.6	690.0	1,049.2	713.2	722.0	792.8	773.2
1914 — May	100.8	99.2	113.6	134.4	91.2	122.8	89.6	127.2	110.4	106.8	124.8	115.2
June	5.6	53.6	2.4	97.2	1.6	12.8	4.0	99.2	0.	6.0	21.6	9.6
July	0.	22.4	0.	32.0	0.	0.8	0.	20.8	0.	0.	8.8	0.
August	5.6	80.8	15.2	208.0	0.	62.4	30.8	171.2	30.4	40.0	117.2	93.6
September	4.8	37.6	38.8	68.8	4.8	52.0	48.8	60.0	52.8	49.6	48.8	55.2
October	0.	3.6	0.	7.6	0.	0.	0.	4.0	0.4	0.	0.	0.
November	0.	12.4	0.	16.4	0.	3.2	0.	8.8	0.4	0.	0.8	0.
December	0.	59.2	0.	75.2	0.	40.0	3.2	34.8	8.8	1.6	4.8	16.0
1915 — January	240.8	198.4	258.8	336.0	290.0	265.2	218.4	254.4	281.2	254.4	287.6	256.2
February	120.4	142.8	248.4	270.8	124.8	120.0	87.6	154.8	124.8	114.0	129.6	166.4
March	15.6	12.0	18.8	10.8	16.8	10.8	8.8	12.8	15.6	10.4	14.4	24.8
April	42.4	12.0	30.8	27.6	31.2	39.6	42.8	12.8	35.2	30.8	33.2	33.6
Totals	536.0	734.0	726.8	1,284.8	560.4	729.6	534.0	960.8	660.0	613.6	791.6	770.6
Grand totals	2,393.9	3,455.4	3,872.7	5,315.6	2,916.2	4,059.6	3,148.3	4,728.1	3,438.7	3,059.2	3,868.1	3,549.6

TABLE 3. FLOW OF DRAINAGE WATER FROM LYSIMETER TANKS 1 TO 12 FROM MAY 1, 1910, TO APRIL 30, 1915
(In acre inches)

Period	Tank											
	1	2	3	4	5	6	7	8	9	10	11	12
May 1, 1910, to April 30, 1911	9.68	18.73	17.54	21.84	12.13	17.33	11.02	16.96	12.23	11.44	12.72	10.82
May 1, 1911, to April 30, 1912	7.44	14.45	15.83	20.60	16.01	14.86	14.69	19.74	15.63	12.01	17.36	16.36
May 1, 1912, to April 30, 1913	13.88	14.32	24.90	29.63	15.58	25.55	21.05	29.34	22.33	18.43	25.42	21.56
May 1, 1913, to April 30, 1914	14.15	18.62	18.18	25.87	13.52	23.17	16.77	25.50	17.33	17.54	19.27	18.79
May 1, 1914, to April 30, 1915	13.02	17.84	17.66	31.22	13.62	17.73	12.98	23.35	16.04	14.91	19.24	18.73
Totals	58.17	83.96	94.11	129.16	70.86	98.64	76.51	114.89	83.56	74.33	94.01	86.26

TABLE 4. METEOROLOGICAL RECORDS AT ITHACA, MAY 1, 1910, TO APRIL 30, 1915
Data by months

Year and month	Rainfall (inches)	Temperature (degrees Fahrenheit)			Hours of sunshine	Average hourly velocity of wind (miles)	Monthly mean humidity of air at 8 a. m. (per cent)
		Mean maximum	Mean minimum	Mean			
1910—May	4.20	65.0	43.4	54.2	231.0	9.6	82
June	1.14	75.2	52.4	63.8	259.1	7.2	68
July	1.62	83.8	59.1	71.4	301.3	8.3	73
August	2.39	80.2	55.3	67.8	276.2	9.6	69
September	4.64	72.2	52.2	62.3	172.3	8.0	80
October	2.29	61.8	41.7	51.8	152.6	11.1	74
November	2.85	39.9	30.0	35.0	30.2	11.3	85
December	2.18	28.4	13.9	21.2	2.3	10.8	92
1911—January	1.96	36.4	20.5	28.4	84.9	13.2	84
February	4.34	34.4	19.8	27.1	75.5	9.0	86
March	1.86	38.7	20.2	29.4	146.4	14.8	79
April	2.05	55.2	33.7	44.4	189.5	9.4	66
May	2.24	77.6	51.4	64.5	291.9	7.6	68
June	3.59	76.7	54.4	65.6	196.4	8.2	74
July	2.53	86.5	60.4	73.4	291.8	7.4	68
August	4.15	79.4	58.3	68.8	165.3	8.6	76
September	2.78	71.3	49.4	60.4	188.5	8.9	83
October	3.30	58.4	40.3	49.4	157.5	9.6	82
November	1.28	43.3	28.8	36.0	83.8	14.5	74
December	1.83	40.9	28.9	34.9	65.5	11.4	78
1912—January	1.63	24.8	8.5	16.6	129.4	12.8	82
February	1.28	31.4	12.7	21.4	178.4	10.0	82
March	2.73	38.8	18.9	28.8	182.0	10.7	82
April	2.97	54.3	34.7	44.5	176.2	12.6	81
May	3.58	69.6	46.4	58.0	279.6	11.1	75
June	1.37	75.0	51.3	63.2	358.6	8.4	69
July	2.64	82.5	59.3	70.9	337.1	7.5	73
August	3.54	74.2	55.2	64.7	260.6	8.1	81
September	7.46	72.1	52.7	62.4	210.2	9.0	88
October	1.86	62.3	42.5	52.4	151.7	9.8	80
November	2.41	48.8	34.7	41.8	80.9	11.2	79
December	1.48	40.1	26.8	33.4	77.1	12.6	78
1913—January	3.15	42.8	26.5	34.7	69.4	13.8	80
February	1.38	31.2	15.2	23.2	118.2	10.0	81
March	3.73	47.1	26.4	36.8	127.6	13.3	82
April	1.49	58.4	37.8	48.1	222.8	12.4	74
May	3.15	66.2	44.5	55.4	286.9	9.8	73
June	2.00	78.6	51.4	65.0	332.2	7.5	68
July	1.59	82.5	68.2	70.4	304.7	8.4	69
August	1.92	82.0	57.2	69.6	304.2	8.2	71
September	3.28	73.0	49.2	61.1	219.7	8.1	76
October	3.63	61.3	45.4	53.4	152.5	9.4	86
November	2.21	51.5	35.8	43.6	101.5	11.9	81
December	1.94	39.8	25.3	32.6	84.9	10.0	83

TABLE 4 (*continued*)

Data by months (*concluded*)

Year and month	Rainfall (inches)	Temperature (degrees Fahrenheit)			Hours of sunshine	Average hourly velocity of wind (miles)	Monthly mean humidity of air at 8 a. m. (per cent)
		Mean maximum	Mean minimum	Mean			
1914—January	1.37	33.7	19.3	26.5	56.7	13.8	85
February	1.62	27.0	8.5	17.8	151.4	11.6	82
March	1.90	39.1	24.3	31.7	141.7	10.3	82
April	4.35	51.1	33.1	42.1	144.8	11.6	78
May	3.63	71.1	47.5	59.3	297.7	8.1	71
June	4.75	76.5	54.5	65.5	301.2	8.5	74
July	1.89	81.2	59.2	70.2	230.8	7.0	78
August	6.10	80.2	58.2	69.2	208.4	7.0	80
September	1.96	71.1	48.2	59.6	255.2	7.6	82
October	1.38	63.6	43.9	53.8	212.5	8.7	86
November	0.68	46.4	31.1	38.8	111.9	12.5	78
December	2.70	32.9	19.1	26.0	73.3	10.4	82
1915—January	5.02	33.4	19.7	26.6	96.0	10.4	85
February	1.83	37.8	22.7	30.2	94.1	11.9	86
March	0.32	37.5	21.9	29.7	183.5	10.9	83
April	0.55	62.7	39.6	51.2	202.2	9.0	70

Average of each month

Month	Rainfall (inches)	Temperature (degrees Fahrenheit)			Hours of sunshine	Average hourly velocity of wind (miles)	Monthly mean humidity of air at 8 a. m. (per cent)
		Mean maximum	Mean minimum	Mean			
May	3.36	69.9	46.6	58.3	277.4	9.2	73.8
June	2.57	76.4	52.8	64.6	289.5	8.0	70.6
July	2.05	83.3	61.2	71.3	293.1	7.7	72.2
August	3.62	79.2	56.8	68.0	242.9	8.3	75.4
September	4.02	71.9	50.3	61.2	209.2	8.3	81.8
October	2.49	61.5	42.8	52.2	165.4	9.7	81.6
November	1.89	46.0	32.1	39.0	81.7	12.3	79.5
December	2.03	36.4	22.8	29.6	60.6	11.0	82.6
January	2.63	34.2	18.9	26.6	87.3	12.8	83.2
February	2.09	32.4	15.8	23.9	123.5	10.5	83.5
March	2.11	40.2	22.3	31.3	156.2	12.0	81.6
April	2.28	56.3	35.8	46.1	187.1	11.0	73.8

TABLE 4 (*concluded*)

Data by years

Year	Total rainfall (inches)	Temperature (degrees Fahrenheit)			Total hours of sunshine	Average hourly velocity of wind (miles)	Mean humidity of air at 8 a. m. (per cent)
		Mean maximum	Mean minimum	Mean			
May 1910, to April 1911............	31.52	55.9	36.9	46.4	1,921.3	10.2	78.2
May 1911, to April 1912............	30.31	57.0	37.2	47.0	2,106.7	10.2	77.5
May 1912, to April 1913............	34.09	58.7	39.6	49.1	2,293.8	10.6	78.3
May 1913, to April 1914............	28.96	57.2	38.5	47.4	2,281.2	10.1	77.8
May 1914, to April 1915............	30.81	57.9	38.8	48.3	2,266.8	9.3	79.6

TABLE 5. EVAPORATION RECORDS AT MOUNT HOPE RESERVOIR, ROCHESTER, NEW YORK

Average of results obtained since the beginning of experiments in 1891

Years	Month	Depth of evaporation (inches)		Mean temperature (degrees Fahrenheit)				Velocity of wind over water surface (miles per hour)	Precipitation (inches)
		In exposed tub	In floating tub	Water in exposed tub	Water in floating tub	Water in reservoir	Air in shade		
1896–1916	January....	......	0.82	......	33.0	32.8	25.8	7.6	1.992
1896–1916	February...	......	0.89	......	32.4	32.2	23.3	7.7	1.465
1896–1916	March.....	......	1.60	......	36.1	34.7	33.8	7.3	1.987
1894–1916	April.......	4.85	2.44	48.8	46.7	43.3	46.9	7.2	2.216
1892–1916	May.......	6.55	3.59	60.5	58.7	54.4	60.0	5.9	2.787
1892–1916	June.......	7.65	4.45	70.1	67.9	64.0	70.1	5.0	2.764
1891–1916	July.......	8.41	5.04	74.0	72.6	69.7	74.7	4.6	3.374
1891–1916	August.....	7.11	4.66	71.4	71.3	70.2	72.0	4.8	3.068
1891–1916	September..	5.36	3.65	64.7	65.6	65.7	65.6	5.0	2.293
1891–1916	October....	3.66	2.59	52.6	54.1	56.0	33.3	5.8	2.415
1895–1916	November..	2.06	1.41	42.0	42.7	45.4	40.2	6.9	1.853
1895–1916	December..	......	1.15	......	34.4	36.3	29.2	7.2	1.680
Totals............		45.65	32.29	......	......	......	......	....	27.894
Means............		......	......	60.5	51.3	50.4	49.6	6.3	....

TABLE 6. RECORDS OF THE UNITED STATES WEATHER BUREAU

At Rochester, New York

Years	Month	Precipitation (inches)		Temperature of air in shade (degrees Fahrenheit)		Humidity of air (per cent)	
		Mean during month	Monthly mean since 1872	Mean during month	Monthly mean since 1872	Mean during month	Monthly mean since 1872
1896–1916	January	2.99	3.10	25.8	24.8	77.5	79.5
1896–1916	February	2.69	2.70	22.8	23.7	77.5	78.5
1896–1916	March	3.08	2.94	33.1	31.5	74.0	75.5
1894–1916	April	2.35	2.41	45.6	44.5	68.0	68.0
1892–1916	May	2.95	2.99	57.2	56.7	67.5	66.5
1892–1916	June	2.72	*2.91	66.2	*66.0	67.5	68.0
1891–1916	July	3.11	*3.05	71.3	*71.0	68.5	*68.5
1891–1916	August	2.98	*2.93	69.0	*68.8	71.0	*70.5
1891–1916	September	2.29	*2.39	63.2	*62.8	74.0	*73.0
1891–1916	October	2.38	*2.77	51.7	*50.9	75.0	74.5
1895–1916	November	2.21	2.53	39.8	38.8	75.5	76.0
1895–1916	December	2.72	2.80	28.9	28.8	77.5	79.0
Total		32.47	....	....	....	....	....
Means		....	*2.80	47.9	*47.4	73.0	*73.0

* Data for one year missing.

At Ithaca, New York

Years	Month	Precipitation during month (inches)	Mean temperature of air in shade during month (degrees Fahrenheit)	Years	Month	Mean humidity of air during month (per cent)	Mean velocity of wind during month (miles per hour)
1896–1916	January	2.19	25.28	1900–1916	January	81.94	10.88
1896–1916	February	2.05	23.00	1900–1916	February	81.35	10.58
1896–1916	March	2.53	32.76	1900–1916	March	83.82	10.21
1896–1916	April	2.50	45.09	1900–1916	April	74.41	9.77
1896–1916	May	3.08	56.85	1900–1916	May	73.64	8.26
1896–1916	June	3.58	64.95	1900–1916	June	73.94	7.18
1896–1916	July	3.17	70.90	1900–1916	July	75.24	6.70
1896–1916	August	3.17	68.23	1900–1916	August	77.70	6.95
1896–1916	September	3.07	62.00	1900–1916	September	80.23	7.58
1896–1916	October	3.02	50.90	1900–1916	October	79.17	8.67
1896–1916	November	2.07	39.14	1900–1916	November	79.35	10.24
1896–1916	December	2.40	28.14	1900–1916	December	81.29	10.17
Total		32.83	....	....	....	....	....
Means		....	47.27	....	....	78.51	8.93

TABLE 7. SUBSTANCES CONTAINED IN DRAINAGE WATER, PARTS PER MILLION, BY FIVE-MONTHS PERIODS (MAY 1 TO SEPTEMBER 30) AND BY SEVEN-MONTHS PERIODS (OCTOBER 1 TO APRIL 30)

	Tank											
	1	2	3	4	5	6	7	8	9	10	11	12
					TOTAL SOLIDS							
1910–11												
May 1–Sept. 30	524	580	394	640	397	416	338	598	430	444	332	456
Oct. 1–Apr. 30	364	678	258	584	280	262	276	592	244	280	276	286
1911–12												
May 1–Sept. 30	278	220	281	263	95	305	168	448	267	288	275	310
Oct. 1–Apr. 30	248	285	220	377	145	228	218	335	225	185	215	230
1912–13												
May 1–Sept. 30	398	498	314	439	290	283	327	447	299	312	269	330
Oct. 1–Apr. 30	361	496	279	374	235	277	291	374	301	308	272	309
1913–14												
May 1–Sept. 30	286	343	229	300	0	224	280	342	273	276	190	288
Oct. 1–Apr. 30	190	440.5	211.5	321	200	184	237	342	231	240	212	231
1914–15												
May 1–Sept. 30	294	476	318	352	305	327	321	342	289	298	315	335
Oct. 1–Apr. 30	254	444	193	271	241	243	287	290	239	179	242	253
Average	319.7	446.1	269.7	392.1	218.8	274.9	274.3	411	279.8	281	259.8	302.8
					NITRATES							
1910–11												
May 1–Sept. 30	38.7	97.1	25.5	64.0	30.0	41.3	24.0	60.0	48.0	50.0	58.3	45.0
Oct. 1–Apr. 30	16.0	160.0	12.0	128.0	14.4	10.8	16.0	120.0	16.0	18.4	13.2	28.8
1911–12												
May 1–Sept. 30	Trace	58.0	5.0	62.0	Trace	6.8	Trace	64.0	4.4	31.5	8.0	14.6
Oct. 1–Apr. 30	6.2	81.1	10.4	83.2	8.0	0.0	7.6	51.2	6.1	0.0	11.2	14.4
1912–13												
May 1–Sept. 30	3.4	166.4	12.0	102.4	3.0	0.9	8.0	83.2	7.2	0.9	5.6	10.0
Oct. 1–Apr. 30	1.6	116.0	11.6	100.0	10.9	0.0	4.5	76.4	2.8	0.0	0.0	0.0
1913–14												
May 1–Sept. 30	1.7	80.0	2.3	62.0	0.0	1.5	2.0	48.0	1.4	0.7	0.7	0.8
Oct. 1–Apr. 30	1.6	125.4	2.4	62.7	3.4	1.2	1.0	58.2	6.5	1.2	1.6	0.4
1914–15												
May 1–Sept. 30	0.9	74.6	1.0	37.7	1.5	1.5	0.8	40.0	1.2	0.7	2.3	0.4
Oct. 1–Apr. 30	4.7	94.0	0.0	48.4	1.3	1.3	4.5	19.2	0.9	0.0	0.0	1.7
Average	7.5	105.3	8.2	75.0	7.3	6.5	6.8	62.0	9.4	10.3	10.0	11.6

					BICARBONATES							
1910–11												
May 1–Sept. 30	322	323	276	380	266	160	266	414	335	351	155	372
Oct. 1–Apr. 30	211	235	182	232	180	187	180	300	182	197	200	165
1911–12												
May 1–Sept. 30	280	123	270	142	113	301	150	351	280	227	278	270
Oct. 1–Apr. 30	216	101	230	162	145	270	236	217	249	212	196	221
1912–13												
May 1–Sept. 30	358	230	312	242	317	310	330	295	313	332	262	315
Oct. 1–Apr. 30	150.3	202.5	245.5	174.4	209.9	276.8	271.8	226.4	297.1	294.5	252	286.9
1913–14												
May 1–Sept. 30	198	185	204	224	0	210	237	284	253	248	172	252
Oct. 1–Apr. 30	119.8	141.3	172.8	170.3	136.8	185.4	179.3	179.8	183.8	189.5	173.3	154.3
1914–15												
May 1–Sept. 30	173	254.7	239.5	216	173	264	263	204	243.5	261.9	231	250.2
Oct. 1–Apr. 30	171.1	194.4	148.7	164.2	194.4	205	227	167.4	207	211.9	196.8	202.3
Average	219.9	199.0	228.0	210.7	173.5	236.9	234.1	263.9	254.3	252.5	211.6	248.9
					SULFATES							
1910–11												
May 1–Sept. 30	Sulfates not determined on tanks 1–9.									13.4	16.6	19.8
Oct. 1–Apr. 30	Sulfates not determined on tanks 1–9.									35	26	29
1911–12												
May 1–Sept. 30	13	15	25	12	7	28	25	43	22	31	31	43
Oct. 1–Apr. 30	19	21	18	26	23	24	22	30	28	21	31	36
1912–13												
May 1–Sept. 30	37	28	12	22	28	25	40	31	28	37	40	43
Oct. 1–Apr. 30	34.2	25	23.8	21.8	40.6	39.9	48.9	32.1	28.5	32.8	30.2	40.6
1913–14												
May 1–Sept. 30	29	25	27	35	0	35	35	43	37	47	34	47
Oct. 1–Apr. 30	36.4	31.8	23.8	19.8	32	25.7	37.5	27.7	44	39.8	41.1	50.6
1914–15												
May 1–Sept. 30	47.2	28.5	26.1	19.6	35.6	23	33.6	16.1	27.2	30.2	45.5	52.4
Oct. 1–Apr. 30	36.3	29.1	25.2	22.8	22.1	24	28.9	22.8	20.9	26.3	39.8	39.8
Average	31.5	25.4	22.6	22.4	23.5	28.1	33.8	30.7	29.4	31.3	33.5	40.1
					SILICA							
1910–11												
May 1–Sept. 30	24.2	9.1	7.3	7.3	7.8	10.6	8.1	10.4	7.7	8.6	24.7	9.1
Oct. 1–Apr. 30	5.8	6.6	4.5	6.6	4.4	4.1	5.3	5.9	5.2	5.1	5.8	5.4
1911–12												
May 1–Sept. 30	2.6	4.5	12.0	6.4	3.3	12.6	2.0	9.2	7.7	8.7	9.7	10.2
Oct. 1–Apr. 30	3.7	3.0	5.9	4.1	3.1	5.8	6.0	6.3	6.1	7.7	8.2	6.6
1912–13												
May 1–Sept. 30	5.5	8.6	9.2	6.8	6.7	7.7	9.5	3.8	7.2	8.0	8.8	8.1
Oct. 1–Apr. 30	2.6	7.3	7.7	5.9	5.1	7.4	7.2	8.2	6.2	6.0	5.6	6.7
1913–14												
May 1–Sept. 30	10.3	5.2	5.9	6.4	0.0	6.2	8.3	13.1	8.1	Lost	4.2	8.3
Oct. 1–Apr. 30	4.0	7.7	8.5	12.3	13.2	13.5	6.2	10.8	7.8	6.8	6.6	6.7
1914–15												
May 1–Sept. 30	22.6	17.0	27.0	15.7	15.7	13.1	12.9	14.7	10.2	10.6	10.2	12.2
Oct. 1–Apr. 30	9.8	7.5	9.8	7.9	7.9	8.5	6.5	8.6	7.3	4.8	5.8	5.6
Average	9.1	7.6	9.8	7.9	6.7	8.9	7.2	9.1	7.3	6.6	9.0	7.9

TABLE 7 (*continued*)

	Tank											
	1	2	3	4	5	6	7	8	9	10	11	12
					PHOSPHATES							
1910–11												
May 1–Sept. 30...........	None	None	None	None	None	None	None	None	None	None	None	None
Oct. 1–Apr. 30...........	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace
1911–12												
May 1–Sept. 30...........	None	None	None	None	None	None	None	None	None	None	None	None
Oct. 1–Apr. 30...........	None	None	None	None	None	None	None	None	None	None	None	None
1912–13												
May 1–Sept. 30...........	None	None	None	None	None	None	None	None	None	None	None	None
Oct. 1–Apr. 30...........	None	None	None	None	None	None	None	None	None	None	None	None
1913–14												
May 1–Sept. 30...........	None	None	None	None	None	None	None	None	Trace	None	None	None
Oct. 1–Apr. 30...........	Trace	Trace	None	None	None	None	None	None	None	None	None	None
1914–15												
May 1–Sept. 30...........	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace
Oct. 1–Apr. 30...........	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace
					CALCIUM							
1910–11												
May 1–Sept. 30...........	26.5	66.6	61.3	108.8	69.3	58.9	58.4	118.5	97.9	103.0	51.4	105.0
Oct. 1–Apr. 30...........	31.0	91.5	52.8	96.3	53.9	53.0	52.6	102.6	52.4	51.3	55.5	53.2
1911–12												
May 1–Sept. 30...........	3.7	17.8	45.7	29.1	5.7	63.8	22.6	89.9	46.4	46.4	58.2	58.7
Oct. 1–Apr. 30...........	5.9	20.9	34.6	53.4	22.8	50.1	39.9	62.1	42.5	34.3	36.4	39.4
1912–13												
May 1–Sept. 30...........	11.6	45.0	51.8	60.0	32.7	54.0	56.8	67.9	50.9	49.5	43.9	54.9
Oct. 1–Apr. 30...........	6.4	49.6	48.4	54.4	26.1	47.3	48.2	64.8	45.2	35.4	50.7	47.0
1913–14												
May 1–Sept. 30...........	15.0	28.9	29.0	49.0	0.0	30.6	32.8	61.5	37.2	19.2	10.6	42.4
Oct. 1–Apr. 30...........	14.2	65.1	41.7	61.5	30.3	45.2	43.2	60.8	46.8	46.9	47.6	47.0
1914–15												
May 1–Sept. 30...........	31.8	76.4	55.2	63.3	40.9	60.0	61.5	60.8	57.6	62.9	66.0	67.2
Oct. 1–Apr. 30...........	45.0	68.1	54.9	62.2	36.9	57.8	63.5	60.4	54.6	51.5	58.2	54.0
Average.............	19.1	53.0	47.5	63.8	31.9	52.1	47.9	74.9	53.1	50.0	47.8	56.9
					MAGNESIUM							
1910–11												
May 1–Sept. 30...........	2.6	5.9	11.2	17.0	19.0	18.6	22.6	24.8	19.2	19.7	17.2	18.7
Oct. 1–Apr. 30...........	8.8	22.0	7.0	14.3	9.1	9.0	9.5	19.9	8.2	8.6	9.6	9.6
1911–12												
May 1–Sept. 30...........	1.5	10.4	11.0	13.7	1.8	12.2	10.5	17.0	10.8	12.1	13.6	12.1
Oct. 1–Apr. 30...........	1.8	13.3	8.1	10.9	7.8	11.0	12.9	11.4	11.5	8.3	10.6	11.1

1912–13												
May 1–Sept. 30	8.3	19.8	8.1	10.8	11.7	9.7	12.4	14.5	13.5	11.6	12.3	12.6
Oct. 1–Apr. 30	7.8	17.5	7.5	9.1	12.1	10.3	12.9	12.7	13.3	12.9	13.0	14.4
1913–14												
May 1–Sept. 30	5.5	14.4	5.7	8.7	0.0	9.8	11.4	13.5	9.8	7.0	5.5	13.3
Oct. 1–Apr. 30	8.3	18.9	6.9	9.6	6.9	8.8	10.5	12.7	10.8	12.2	11.4	11.4
1914–15												
May 1–Sept. 30	10.2	14.7	7.0	8.0	9.1	9.7	11.8	10.3	12.4	13.2	12.6	14.0
Oct. 1–Apr. 30	10.2	13.6	4.5	7.3	7.7	8.1	10.9	9.5	9.5	10.1	10.5	11.1
Average	6.5	15.1	7.7	10.9	8.5	10.7	12.5	14.6	11.9	11.6	11.6	12.8
					POTASSIUM							
1910–11												
May 1–Sept. 30	18.6	3.4	1.1	1.2	0.6	0.6	1.3	2.1	1.6	1.8	1.6	0.8
Oct. 1–Apr. 30	27.4	3.6	1.6	3.1	0.6	1.2	3.0	1.2	3.7	6.8	2.5	2.5
1911–12												
May 1–Sept. 30	51.6	12.5	12.1	10.3	8.2	9.5	11.1	8.5	15.8	16.0	11.0	10.0
Oct. 1–Apr. 30	41.9	10.0	11.1	9.0	7.1	7.1	9.8	6.6	13.0	10.6	9.1	1.2
1912–13												
May 1–Sept. 30	65.2	19.0	21.9	15.0	21.4	16.4	22.0	12.4	19.1	25.7	14.7	21.0
Oct. 1–Apr. 30	30.2	14.3	13.2	11.9	17.9	8.9	14.1	7.4	12.6	17.3	9.9	13.8
1913–14												
May 1–Sept. 30	17.8	20.2	20.6	19.0	0.0	21.7	14.4	13.2	18.1	9.8	6.4	13.8
Oct. 1–Apr. 30	18.6	18.7	14.9	16.4	15.0	12.6	12.4	11.5	12.6	13.4	11.3	11.8
1914–15												
May 1–Sept. 30	29.2	19.1	23.2	23.1	23.3	20.2	22.9	17.0	19.4	19.0	18.5	15.5
Oct. 1–Apr. 30	24.5	15.3	14.1	13.2	18.1	15.0	15.5	11.6	11.1	14.9	10.0	11.6
Average	32.5	13.6	13.4	12.2	11.2	11.3	12.6	9.1	12.7	13.5	9.5	10.2
					SODIUM							
1910–11												
May 1–Sept. 30	69.2	48.9	28.7	34.7	15.9	14.2	6.6	6.3	10.1	14.4	19.4	26.6
Oct. 1–Apr. 30	47.9	34.6	24.6	24.3	20.6	15.5	18.6	18.5	20.5	19.4	19.5	18.2
1911–12												
May 1–Sept. 30	60.1	30.2	28.6	24.6	23.8	21.6	17.1	15.9	20.0	20.2	18.7	19.6
Oct. 1–Apr. 30	44.4	25.2	20.0	13.6	12.5	17.4	17.2	14.8	14.5	12.9	14.8	8.9
1912–13												
May 1–Sept. 30	69.0	35.6	27.6	23.0	32.8	23.9	27.3	18.3	24.8	26.1	19.7	26.3
Oct. 1–Apr. 30	53.2	35.4	26.6	20.5	23.8	16.1	21.7	16.9	22.0	24.2	19.5	23.8
1913–14												
May 1–Sept. 30	44.8	28.4	21.0	20.3	0.0	19.0	28.0	17.4	20.3	8.6	7.2	21.4
Oct. 1–Apr. 30	29.0	29.1	24.6	25.3	26.7	23.2	22.5	19.1	25.5	27.5	24.4	25.2
1914–15												
May 1–Sept. 30	33.6	21.1	20.3	17.7	25.0	16.0	17.0	11.3	20.3	19.9	18.6	20.0
Oct. 1–Apr. 30	30.9	22.5	18.2	16.4	19.1	16.7	20.2	12.1	19.4	18.6	21.2	19.9
Average	48.2	31.1	24.0	22.0	20.0	18.4	19.6	15.1	19.7	19.2	18.3	21.1

TABLE 7 (*concluded*)

	Tank											
	1	2	3	4	5	6	7	8	9	10	11	12
					CARBONATES							
1910–11												
May 1–Sept. 30...........	None	None	None	None	None	None	None	None	None	None	None	None
Oct. 1–Apr. 30...........	None	None	None	None	None	None	None	None	None	None	None	None
1911–12												
May 1–Sept. 30...........	None	None	None	None	None	None	None	None	None	None	None	None
Oct. 1–Apr. 30...........	None	None	None	None	None	None	None	None	None	None	None	None
1912–13												
May 1–Sept. 30...........	None	None	None	None	None	None	None	None	None	None	None	None
Oct. 1–Apr. 30...........	None	None	None	None	None	None	None	None	None	None	None	None
1913–14												
May 1–Sept. 30...........	None	None	None	None	None	None	None	None	None	None	None	None
Oct. 1–Apr. 30...........	None	None	None	None	None	None	None	None	None	None	None	None
1914–15												
May 1–Sept. 30...........	6.6	2.9	5.4	3.9	8.6	7.1	5.9	Trace	5.4	4.9	7.4	Trace
Oct. 1–Apr. 30...........	0.0	0.0	0.0	0.0	3.8	2.2	4.2	0.0	0.0	0.0	0.0	None

TABLE 8. SUBSTANCES CONTAINED IN DRAINAGE WATER, CALCULATED TO POUNDS PER ACRE, BY FIVE-MONTHS PERIODS (MAY 1 TO SEPTEMBER 30), BY SEVEN-MONTHS PERIODS (OCTOBER 1 TO APRIL 30), AND BY YEARLY PERIODS (MAY 1 TO APRIL 30)

	Tank											
	1	2	3	4	5	6	7	8	9	10	11	12
					TOTAL SOLIDS							
1910–11												
May 1–Sept. 30	204.7	343.4	181.0	468.3	146.4	197.0	119.4	403.1	158.9	154.1	134.4	177.4
Oct. 1–Apr. 30	623.4	2,409.2	853.1	2,335.0	626.7	857.2	554.0	1,794.5	565.2	598.9	650.0	561.2
Total	828.1	2,752.6	1,034.1	2,803.3	773.1	1,054.2	673.4	2,197.6	724.1	753.0	784.4	738.6
1911–12												
May 1–Sept. 30	104.7	195.1	183.9	373.5	66.4	138.1	101.4	643.6	238.6	43.1	324.3	242.1
Oct. 1–Apr. 30	324.1	679.7	644.2	1,222.5	424.3	663.6	593.3	1,015.6	595.0	475.4	591.3	672.0
Total	428.8	874.8	828.1	1,596.0	490.7	801.7	694.7	1,659.2	833.6	518.5	915.6	914.1
1912–13												
May 1–Sept. 30	393.1	700.1	572.7	1,258.4	236.7	549.8	474.8	1,239.1	408.5	339.1	550.4	546.7
Oct. 1–Apr. 30	779.1	912.0	1,065.9	1,439.2	638.3	1,066.2	966.1	1,450.3	1,112.2	952.0	1,010.4	998.0
Total	1,172.2	1,612.1	1,638.6	2,697.6	875.0	1,616.0	1,440.9	2,689.4	1,520.7	1,291.1	1,560.8	1,544.7
1913–14												
May 1–Sept. 30	20.1	146.4	25.7	233.6	0.0	85.7	29.6	258.8	24.6	51.0	41.0	25.3
Oct. 1–Apr. 30	596.5	1,672.2	848.1	1,633.3	613.3	896.5	876.2	1,718.3	887.1	910.6	880.5	964.0
Total	616.6	1,818.6	873.8	1,866.9	613.3	982.2	905.8	1,977.1	911.7	961.6	921.5	989.3
1914–15												
May 1–Sept. 30	188.9	768.7	297.3	1,046.2	163.7	451.1	305.8	899.9	307.7	331.7	556.5	504.1
Oct. 1–Apr. 30	585.8	1,075.3	591.3	1,109.4	613.3	640.2	569.8	769.5	613.3	404.8	625.9	691.4
Total	774.7	1,844.0	888.6	2,155.6	777.0	1,091.3	875.6	1,669.4	921.0	736.5	1,182.4	1,195.5
Yearly average	764.1	1,780.4	1,052.6	2,223.9	705.8	1,109.1	918.1	2,038.5	982.2	852.1	1,072.9	1,076.4
					NITRATES							
1910–11												
May 1–Sept. 30	15.1	57.5	11.7	46.8	11.1	19.6	8.5	40.5	17.7	17.3	23.6	17.5
Oct. 1–Apr. 30	27.4	568.6	39.7	512.0	32.2	35.3	32.1	364.0	37.0	39.4	31.1	56.0
Total	42.5	626.1	51.4	558.8	43.3	54.9	40.6	404.5	54.7	56.7	54.7	73.5
1911–12												
May 1–Sept. 30	Trace	51.4	3.3	88.1	Trace	3.1	Trace	91.9	3.9	4.7	9.4	11.4
Oct. 1–Apr. 30	8.1	193.4	30.5	269.8	23.4	0.0	20.7	155.2	16.1	0.0	30.8	42.1
Total	8.1	244.8	33.8	357.9	23.4	3.1	20.7	247.1	20.0	4.7	40.2	53.5

TABLE 8 (*continued*)

	Tank											
	1	2	3	4	5	6	7	8	9	10	11	12
	NITRATES (*concluded*)											
1912–13												
May 1–Sept. 30	3.4	233.9	21.9	293.5	2.5	1.8	11.6	230.6	9.8	1.0	11.5	16.6
Oct. 1–Apr. 30	3.5	213.3	44.3	384.8	29.7	0.0	14.8	296.3	10.3	0.0	0.0	0.0
Total	6.9	447.2	66.2	678.3	32.2	1.8	26.4	526.9	20.1	1.0	11.5	16.6
1913–14												
May 1–Sept. 30	0.1	34.1	0.3	48.3	0.0	0.6	0.2	36.3	0.1	0.1	0.1	0.1
Oct. 1–Apr. 30	5.0	476.1	9.6	319.1	10.5	5.8	3.7	292.6	24.9	4.6	6.6	1.8
Total	5.1	510.2	9.9	367.4	10.5	6.4	3.9	328.9	25.0	4.7	6.7	1.9
1914–15												
May 1–Sept. 30	0.6	120.5	0.9	112.0	0.8	2.1	0.8	105.3	1.3	0.8	4.1	0.6
Oct. 1–Apr. 30	11.0	227.7	0.0	198.0	3.3	3.3	8.8	51.2	2.2	0.0	0.0	4.4
Total	11.6	348.2	0.9	310.0	4.1	5.4	9.6	156.5	3.5	0.8	4.1	5.0
Yearly average	14.8	435.3	32.4	454.5	22.7	14.3	20.2	332.8	24.6	13.6	23.4	30.1
	BICARBONATES											
1910–11												
May 1–Sept. 30	125.8	191.2	126.8	278.0	98.3	75.8	93.9	279.4	123.8	121.9	62.8	144.7
Oct. 1–Apr. 30	361.5	835.1	601.8	927.6	402.9	612.4	361.3	909.6	421.6	421.4	471.0	324.0
Total	487.3	1,026.3	728.6	1,205.6	501.2	688.2	455.2	1,189.0	545.4	543.3	533.8	468.7
1911–12												
May 1–Sept. 30	105.5	109.1	176.7	201.7	78.9	136.3	90.5	504.3	250.3	34.0	327.8	210.9
Oct. 1–Apr. 30	282.3	240.9	673.5	525.3	424.3	785.9	642.3	657.9	658.5	544.8	539.0	645.7
Total	387.8	350.0	850.2	727.0	503.2	922.2	732.8	1,162.2	908.8	578.8	866.8	856.6
1912–13												
May 1–Sept. 30	353.6	323.3	569.0	693.7	258.7	602.2	479.2	817.7	427.6	360.8	536.1	521.8
Oct. 1–Apr. 30	324.4	372.3	937.9	671.1	570.1	1,065.5	902.4	877.9	1,097.8	910.3	936.1	926.6
Total	678.0	695.6	1,506.9	1,364.8	828.8	1,667.7	1,381.6	1,695.6	1,525.4	1,271.1	1,472.2	1,448.4
1913–14												
May 1–Sept. 30	13.9	79.0	22.9	174.4	0.0	80.4	25.0	214.9	22.8	45.8	37.1	22.2
Oct. 1–Apr. 30	376.1	536.4	693.0	866.5	419.5	903.8	662.9	903.4	705.9	719.0	719.8	643.9
Total	390.0	615.4	715.9	1,040.9	419.5	983.7	687.9	1,118.3	728.7	764.8	756.9	666.1

1914–15												
May 1–Sept. 30	111.1	411.3	223.9	642.0	92.9	364.2	250.5	536.8	259.3	291.4	408.1	376.6
Oct. 1–Apr. 30	394.4	470.8	455.4	672.1	495.0	540.1	452.1	444.4	530.8	479.1	509.3	552.8
Total	505.5	882.1	679.3	1,314.1	587.9	904.3	702.6	981.2	790.1	770.5	917.4	929.4
Yearly average	489.5	713.9	896.2	1,130.5	568.1	1,033.2	792.0	1,229.3	899.7	785.7	909.4	873.8

SULFATES

1910–11												
May 1–Sept. 30	......	......	......	......	......	......	......	......	......	4.6	6.7	7.7
Oct. 1–Apr. 30	......	......	......	......	......	......	......	......	......	74.8	61.2	56.8
Total	......	......	......	......	......	......	......	......	......	79.4	67.9	64.5
1911–12												
May 1–Sept. 30	4.9	13.3	16.4	17.0	4.9	12.7	15.1	61.8	19.7	4.6	36.6	33.6
Oct. 1–Apr. 30	24.8	50.1	52.7	84.3	67.3	69.9	59.9	91.0	74.0	54.0	85.3	105.2
Total	29.7	63.4	69.1	101.3	72.2	82.6	75.0	152.8	93.7	58.6	121.9	138.8
1912–13												
May 1–Sept. 30	36.6	39.4	21.9	63.1	22.9	48.6	58.1	85.9	38.3	40.2	81.8	71.2
Oct. 1–Apr. 30	73.8	46.0	90.9	83.9	110.3	153.6	162.4	124.5	105.3	101.4	112.2	131.1
Total	110.4	85.4	112.8	147.0	133.2	202.2	220.5	210.4	143.6	141.6	194.0	202.3
1913–14												
May 1–Sept. 30	2.0	10.7	3.0	27.3	0.0	13.4	3.7	32.5	3.3	8.7	7.3	4.1
Oct. 1–Apr. 30	114.3	120.7	95.4	100.7	98.1	125.2	138.6	139.2	169.0	151.0	170.7	211.2
Total	116.3	131.4	98.4	128.0	98.1	138.6	142.3	171.7	172.3	159.7	178.0	215.3
1914–15												
May 1–Sept. 30	30.3	46.0	24.4	58.4	19.1	31.7	32.0	42.4	29.0	33.6	80.4	78.9
Oct. 1–Apr. 30	83.6	70.4	77.0	93.5	56.1	63.3	57.2	60.5	53.9	59.4	102.9	108.9
Total	113.9	116.4	101.4	151.9	75.2	95.0	89.2	102.9	82.9	93.0	183.3	187.8
Yearly average	92.6	99.2	95.4	132.0	94.7	129.6	131.7	159.4	123.1	106.5	149.0	161.7

SILICA

1910–11												
May 1–Sept. 30	9.5	5.4	3.4	5.3	2.9	5.0	2.9	7.0	2.9	3.0	10.0	3.5
Oct. 1–Apr. 30	9.9	23.5	14.9	26.4	9.8	13.4	10.6	17.9	12.0	10.9	13.7	10.6
Total	19.4	28.9	18.3	31.7	12.7	18.4	13.5	24.9	14.9	13.9	23.7	14.1
1911–12												
May 1–Sept. 30	1.0	4.0	7.9	9.1	2.3	5.7	1.2	13.2	6.9	1.3	11.4	8.0
Oct. 1–Apr. 30	4.8	7.2	17.3	13.3	9.1	16.9	16.3	19.1	16.1	19.8	22.6	19.3
Total	5.8	11.2	25.2	22.4	11.4	22.6	17.5	32.3	23.0	21.1	34.0	27.3
1912–13												
May 1–Sept. 30	5.4	12.1	16.8	19.5	5.5	15.0	13.8	10.5	9.8	8.7	18.0	13.4
Oct. 1–Apr. 30	5.6	13.4	29.4	22.7	13.9	28.5	23.9	31.8	22.9	18.5	20.8	21.6
Total	11.0	25.5	46.2	42.2	19.4	43.5	37.7	42.3	32.7	27.2	38.8	35.0

TABLE 8 (*continued*)

	Tank											
	1	2	3	4	5	6	7	8	9	10	11	12
	SILICA (*concluded*)											
1913–14												
May 1–Sept. 30	0.7	2.2	0.7	5.0	0.0	2.4	0.9	9.9	0.7	Lost	0.9	0.7
Oct. 1–Apr. 30	12.6	29.2	34.1	62.6	40.5	65.8	22.9	54.3	30.0	25.8	27.4	28.0
Total	13.3	31.4	34.8	67.6	40.5	68.2	23.8	64.2	30.7	25.8	28.3	28.7
1914–15												
May 1–Sept. 30	14.5	27.5	25.3	46.7	8.4	18.1	12.3	38.7	10.9	11.8	18.0	18.4
Oct. 1–Apr. 30	22.6	18.2	30.3	32.5	20.4	22.6	13.2	23.1	18.7	11.0	14.9	15.4
Total	37.1	45.7	55.6	79.2	28.8	40.7	25.5	61.8	29.6	22.8	32.9	33.8
Yearly average	17.3	28.5	36.0	48.6	22.6	38.7	23.6	45.1	26.2	22.2	31.5	27.8
	PHOSPHATES											
1910–11												
May 1–Sept. 30	None	None	None	None	None	None	None	None	None	None	None	None
Oct. 1–Apr. 30	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace
Total	......	......	......	......	......	......	......	......	......	......	......	......
1911–12												
May 1–Sept. 30	None	None	None	None	None	None	None	None	None	None	None	None
Oct. 1–Apr. 30	None	None	None	None	None	None	None	None	None	None	None	None
Total	......	......	......	......	......	......	......	......	......	......	......	......
1912–13												
May 1–Sept. 30	None	None	None	None	None	None	None	None	None	None	None	None
Oct. 1–Apr. 30	None	None	None	None	None	None	None	None	None	None	None	None
Total	......	......	......	......	......	......	......	......	......	......	......	......
1913–14												
May 1–Sept. 30	None	None	None	None	None	None	None	None	Trace	None	None	None
Oct. 1–Apr. 30	Trace	Trace	None	None	None	None	None	None	None	None	None	None
Total	......	......	......	......	......	......	......	......	......	......	......	......
1914–15												
May 1–Sept. 30	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace
Oct. 1–Apr. 30	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace	Trace
Total	......	......	......	......	......	......	......	......	......	......	......	......

					CALCIUM							
1910–11												
May 1–Sept. 30	10.4	39.4	28.1	79.6	25.6	27.9	20.7	80.0	36.2	35.7	20.8	40.9
Oct. 1–Apr. 30	53.1	325.1	174.6	385.0	120.1	173.6	105.6	311.0	121.4	109.7	130.7	104.8
Total	63.5	364.5	202.7	464.6	145.7	201.5	126.3	391.0	157.6	145.4	151.5	145.7
1911–12												
May 1–Sept. 30	1.4	15.8	30.0	41.3	4.0	28.9	13.6	129.2	41.5	6.9	68.6	45.8
Oct. 1–Apr. 30	7.7	49.8	101.3	173.2	66.7	145.8	108.6	188.3	112.4	88.1	100.1	115.1
Total	9.1	65.6	131.3	214.5	70.7	174.7	122.2	317.5	153.9	95.0	168.7	160.9
1912–13												
May 1–Sept. 30	11.5	63.3	94.5	172.0	26.7	104.9	82.5	188.2	69.5	53.8	89.8	91.0
Oct. 1–Apr. 30	13.9	91.2	184.9	209.3	70.9	182.1	160.0	251.3	167.0	109.4	188.3	151.8
Total	25.4	154.5	279.4	381.3	97.6	287.0	242.5	439.5	236.5	163.2	278.1	242.8
1913–14												
May 1–Sept. 30	1.1	12.3	3.3	38.2	0.0	11.7	3.5	46.5	3.4	3.5	2.3	3.7
Oct. 1–Apr. 30	44.6	247.2	167.1	312.8	92.9	220.1	159.9	305.3	179.8	177.9	197.7	196.3
Total	45.7	259.5	170.4	351.0	92.9	231.8	163.4	351.8	183.2	181.4	200.0	200.0
1914–15												
May 1–Sept. 30	20.4	123.4	51.6	188.1	22.0	82.8	58.6	160.0	61.3	70.0	116.6	101.1
Oct. 1–Apr. 30	104.0	165.0	168.3	254.7	94.1	152.4	126.0	160.1	140.3	116.6	150.7	148.0
Total	124.4	288.4	219.9	442.8	116.1	235.2	184.6	320.1	201.6	186.6	267.3	249.1
Yearly average	53.6	226.5	200.7	370.8	104.6	226.0	167.8	364.0	186.6	154.3	213.1	199.7
					MAGNESIUM							
1910–11												
May 1–Sept. 30	1.0	3.5	5.1	12.4	7.0	8.8	8.0	16.7	7.1	6.8	6.9	7.3
Oct. 1–Apr. 30	15.1	78.2	23.1	57.2	20.4	29.4	19.1	60.3	19.0	18.4	22.6	18.8
Total	16.1	81.7	28.2	69.6	27.4	38.2	27.1	77.0	26.1	25.2	29.5	26.1
1911–12												
May 1–Sept. 30	0.6	9.2	7.2	19.5	1.3	5.5	6.1	24.4	9.7	1.8	16.0	9.5
Oct. 1–Apr. 30	2.4	31.7	23.7	35.4	22.8	32.0	35.1	34.6	30.4	21.3	29.2	32.4
Total	3.0	40.9	30.9	54.9	24.1	37.5	41.2	59.0	40.1	23.1	45.2	41.9
1912–13												
May 1–Sept. 30	8.2	27.8	14.8	31.0	9.6	18.8	18.0	40.2	18.4	12.6	25.2	20.9
Oct. 1–Apr. 30	16.8	32.2	28.7	35.0	32.9	39.6	42.8	49.3	49.1	39.9	48.3	46.5
Total	25.0	60.0	43.5	66.0	42.5	58.4	60.8	89.5	67.5	52.5	73.5	67.4
1913–14												
May 1–Sept. 30	0.4	6.1	0.6	6.8	0.0	3.8	1.2	10.2	0.9	1.3	1.2	1.2
Oct. 1–Apr. 30	26.1	71.8	27.6	49.0	21.2	42.8	39.0	64.0	41.7	46.5	47.3	47.5
Total	26.5	77.9	28.2	55.8	21.2	46.6	40.2	74.2	42.6	47.8	48.5	48.7

TABLE 8 (*concluded*)

	Tank											
	1	2	3	4	5	6	7	8	9	10	11	12
	MAGNESIUM (*concluded*)											
1914–15												
May 1–Sept. 30	6.6	23.7	6.6	23.8	4.9	13.4	11.2	27.1	13.2	14.7	22.3	21.1
Oct. 1–Apr. 30	23.7	33.0	13.8	29.7	19.8	21.5	22.0	25.3	24.8	22.6	27.0	30.3
Total	30.3	56.7	20.4	53.5	24.7	34.9	33.2	52.4	38.0	37.3	49.3	51.4
Yearly average	20.2	63.4	30.2	60.0	28.0	43.1	40.5	70.4	42.9	37.2	49.2	47.1
	POTASSIUM											
1910–11												
May 1–Sept. 30	7.3	2.0	0.5	0.9	0.2	0.3	0.4	1.4	0.6	0.6	0.7	0.3
Oct. 1–Apr. 30	46.9	12.8	5.3	12.4	1.3	3.9	6.0	3.6	8.6	14.5	5.9	4.9
Total	54.2	14.8	5.8	13.3	1.5	4.2	6.4	5.0	9.2	15.1	6.6	5.2
1911–12												
May 1–Sept. 30	19.4	11.1	7.9	14.6	5.7	4.3	6.7	12.2	14.1	2.4	13.0	7.8
Oct. 1–Apr. 30	54.8	23.9	32.5	29.2	20.8	20.7	26.7	20.0	34.4	27.2	25.0	3.5
Total	74.2	35.0	40.4	43.8	26.5	25.0	33.4	32.2	48.5	29.6	38.0	11.3
1912–13												
May 1–Sept. 30	64.4	26.7	39.9	43.0	17.5	31.9	31.9	34.4	26.1	27.9	30.1	34.8
Oct. 1–Apr. 30	65.2	26.3	50.4	45.8	48.6	34.1	46.8	28.9	46.6	53.5	36.8	44.6
Total	129.6	53.0	90.3	88.8	66.1	66.0	78.7	63.3	72.7	81.4	66.9	79.4
1913–14												
May 1–Sept. 30	1.3	8.6	2.3	14.8	0.0	8.3	1.5	10.0	1.6	1.8	1.4	1.2
Oct. 1–Apr. 30	58.4	71.1	59.7	83.4	45.9	61.3	45.8	57.8	48.5	50.8	47.1	49.2
Total	59.7	79.7	62.0	98.2	45.9	69.6	47.3	67.8	50.1	52.6	48.5	50.4
1914–15												
May 1–Sept. 30	18.8	30.8	21.7	68.7	12.5	27.9	21.8	44.7	20.7	21.2	32.7	23.3
Oct. 1–Apr. 30	56.7	36.9	43.5	53.9	46.2	39.6	30.8	30.8	28.6	34.1	25.9	31.9
Total	75.5	67.7	65.2	122.6	58.7	67.5	52.6	75.5	49.3	55.3	58.6	55.2
Yearly average	78.6	50.0	52.7	73.3	39.7	46.5	43.7	48.7	45.9	46.8	43.7	40.3

					SODIUM							
1910–11												
May 1–Sept. 30	27.0	29.0	13.2	25.4	5.8	6.7	2.3	4.2	3.7	5.0	7.9	10.4
Oct. 1–Apr. 30	82.1	123.0	81.3	97.2	46.1	50.8	37.3	56.1	47.5	41.4	45.9	35.7
Total	109.1	152.0	94.5	122.6	51.9	57.5	39.6	60.3	51.2	46.4	53.8	46.1
1911–12												
May 1–Sept. 30	22.6	26.8	18.7	34.9	16.6	9.8	10.3	22.8	17.9	3.0	22.1	15.3
Oct. 1–Apr. 30	58.0	60.1	58.6	45.0	36.6	50.6	46.8	44.9	38.3	33.2	40.7	26.0
Total	80.6	86.9	77.3	79.9	53.2	60.4	57.1	67.7	56.2	36.2	62.8	41.3
1912–13												
May 1–Sept. 30	68.2	50.1	50.3	65.9	26.8	46.4	39.6	50.7	33.9	28.4	40.3	43.6
Oct. 1–Apr. 30	114.8	65.1	101.6	78.9	64.6	62.0	72.0	65.5	81.3	74.8	72.4	76.9
Total	183.0	115.2	151.9	144.8	91.4	108.4	111.6	116.2	115.2	103.2	112.7	120.5
1913–14												
May 1–Sept. 30	3.2	12.1	2.4	15.8	0.0	7.3	3.0	13.2	1.8	1.6	1.6	1.9
Oct. 1–Apr. 30	91.0	110.4	98.6	128.7	81.9	112.9	83.3	95.8	98.0	104.3	101.5	104.8
Total	94.2	122.5	101.0	144.5	81.9	120.2	86.3	109.0	99.8	105.9	103.1	106.7
1914–15												
May 1–Sept. 30	21.6	34.1	19.0	52.6	13.4	22.1	16.2	29.7	21.6	22.2	32.9	30.1
Oct. 1–Apr. 30	71.5	54.5	55.6	67.7	48.4	44.0	40.2	31.9	49.5	42.4	55.0	54.5
Total	93.1	88.6	74.6	120.3	61.8	66.1	56.4	61.6	71.1	64.6	87.9	84.6
Yearly average	112.0	113.0	99.9	122.4	68.0	82.5	70.2	82.9	78.7	71.3	84.1	79.8
					CARBONATES							
1910–11												
May 1–Sept. 30	None	None	None	None	None	None	None	None	None	None	None	None
Oct. 1–Apr. 30	None	None	None	None	None	None	None	None	None	None	None	None
1911–12												
May 1–Sept. 30	None	None	None	None	None	None	None	None	None	None	None	None
Oct. 1–Apr. 30	None	None	None	None	None	None	None	None	None	None	None	None
1912–13												
May 1–Sept. 30	None	None	None	None	None	None	None	None	None	None	None	None
Oct. 1–Apr. 30	None	None	None	None	None	None	None	None	None	None	None	None
1913–14												
May 1–Sept. 30	None	None	None	None	None	None	None	None	None	None	None	None
Oct. 1–Apr. 30	None	None	None	None	None	None	None	None	None	None	None	None
1914–15												
May 1–Sept. 30	4.3	4.8	5.1	11.7	4.6	9.9	5.6	Trace	5.8	5.5	13.0	Trace
Oct. 1–Apr. 30	0.0	0.0	0.0	0.0	9.9	6.1	8.3	None	0.0	0.0	0.0	None
Total	4.3	4.8	5.1	11.7	14.5	16.0	13.9	Trace	5.8	5.5	13.0	Trace

TABLE 9. ASH AND ASH CONSTITUENTS IN CROPS BY YEARS
(In percentage of dry matter)

Tank	Crop	Part of crop	Ash	Ca	Mg	Na	K	S	P
1910									
1	Maize........	Grain..	1.60	0.01	0.08	0.04	0.33	0.15	0.59
		Straw..	5.96	0.39	0.24	0.06	1.39	0.20	0.32
3	Maize........	Grain..	1.54	0.01	0.09	0.04	0.36	0.14	0.65
		Straw..	6.79	0.41	0.21	0.10	1.66	0.19	0.22
5	Maize........	Grain..	1.46	0.01	0.09	0.05	0.34	0.12	0.58
		Straw..	6.77	0.43	0.23	0.10	1.79	0.17	0.22
6	Oats.........	Grain..	4.45	0.01	0.08	0.05	0.69	0.18	0.90
		Straw..	8.60	0.42	0.17	0.46	2.33	0.24	0.22
7	Maize........	Grain..	1.53	0.01	0.10	0.05	0.35	0.17	0.63
		Straw..	6.43	0.43	0.22	0.10	1.69	0.09	0.25
9	Maize........	Grain..	1.47	0.01	0.10	0.05	0.33	0.11	0.58
		Straw..	7.02	0.46	0.23	0.08	1.81	0.10	0.26
10	Oats.........	Grain..	4.17	0.01	0.09	0.07	0.69	0.23	0.92
		Straw..	9.22	0.43	0.17	0.49	2.35	0.19	0.24
11	Maize........	Grain..	1.43	0.01	0.09	0.04	0.32	0.16	0.57
		Straw..	6.98	0.43	0.22	0.06	1.94	0.10	0.28
12	Maize........	Grain..	1.41	0.00	0.10	0.04	0.32	0.14	0.59
		Straw..	7.51	0.50	0.26	0.08	2.07	0.14	0.32
1911									
1	Oats.........	Grain..	4.58	0.12	0.15	0.22	0.55	0.24	0.41
		Straw..	10.38	0.43	0.18	0.43	3.38	0.28	0.34
3	Oats.........	Grain..	4.91	0.11	0.15	0.07	0.67	0.22	0.39
		Straw..	9.61	0.38	0.14	0.31	3.26	0.23	0.33
5	Oats.........	Grain..	4.98	0.10	0.15	0.07	0.64	0.25	0.41
		Straw..	9.37	0.40	0.17	0.31	3.16	0.28	0.51
6	Grass........	Hay...	7.37	0.24	0.13	0.36	1.67	0.26	0.60
7	Oats.........	Grain..	4.90	0.11	0.15	0.06	0.64	0.25	0.41
		Straw..	8.95	0.43	0.16	0.28	2.98	0.27	0.49
9	Oats.........	Grain..	5.01	0.11	0.15	0.07	0.69	0.24	0.40
		Straw..	9.63	0.36	0.14	0.23	3.36	0.21	0.49
10	Grass........	Hay...	6.95	0.26	0.13	0.38	1.56	0.27	0.54
11	Oats.........	Grain..	5.07	0.10	0.13	0.03	0.65	0.21	0.40
		Straw..	10.74	0.35	0.14	0.29	3.28	0.26	0.49
12	Oats.........	Grain..	5.33	0.11	0.13	0.05	0.67	0.23	0.41
		Straw..	10.16	0.39	0.16	0.26	3.25	0.29	0.49
1912									
1	Wheat.......	Hay...	11.69	0.26	0.12	0.11	3.81	0.41	0.34
	Second growth	Hay...	10.28	0.22	0.12	0.16	1.94	0.33	0.29
3	Wheat.......	Hay...	11.14	0.20	0.09	0.11	3.72	0.36	0.39
	Second growth	Hay...	9.23	0.09	0.07	0.04	1.65	0.34	0.41
5	Wheat.......	Hay...	10.60	0.15	0.07	0.18	2.96	0.32	0.41
	Second growth	Hay...	5.72	0.12	0.08	0.14	1.84	0.36	0.42
6	Grass........	Hay...	6.99	0.26	0.10	0.14	1.44	0.24	0.18
7	Wheat.......	Hay...	10.89	0.15	0.07	0.19	3.39	0.33	0.44
	Second growth	Hay...	9.84	0.13	0.09	0.13	1.65	0.27	0.35
9	Wheat.......	Hay...	11.26	0.27	0.14	0.23	3.28	0.32	0.45
	Second growth	Hay...	9.75	0.27	0.12	0.10	1.74	0.26	0.28

TABLE 9 (*concluded*)

Tank	Crop	Part of crop	Ash	Ca	Mg	Na	K	S	P
1912									
10	Grass........	Hay...	7.65	0.34	0.12	0.15	1.83	0.28	0.18
11	Wheat.......	Hay...	11.09	0.34	0.14	0.35	3.26	0.38	0.43
	Second growth	Hay...	8.88	0.20	0.10	0.22	1.76	0.33	0.26
12	Wheat.......	Hay...	11.13	0.24	0.11	0.07	3.47	0.33	0.41
	Second growth	Hay...	5.80	0.11	0.08	0.19	1.64	0.44	0.38
1913									
1	Timothy.....	Hay...	6.21	0.27	0.09	0.28	1.36	0.21	0.18
3	Timothy.....	Hay...	5.97	0.19	0.07	0.30	1.26	0.15	0.19
5	Timothy.....	Hay...	5.70	0.19	0.07	0.18	1.56	0.14	0.20
	Clover.......	Hay...	8.90	1.67	0.36	0.22	1.73	0.16	0.16
6	Grass........	Hay...	7.68	0.19	0.09	0.20	0.98	0.22	0.18
7	Timothy.....	Hay...	6.22	0.18	0.06	0.18	1.34	0.21	0.17
9	Timothy.....	Hay...	6.07	0.13	0.05	0.19	1.60	0.13	0.19
	Clover.......	Hay...	9.20	1.73	0.29	0.25	1.98	0.18	0.18
10	Grass........	Hay...	7.77	0.23	0.06	0.19	0.84	0.26	0.18
11	Timothy.....	Hay...	6.37	0.16	0.05	0.20	1.43	0.18	0.18
12	Timothy.....	Hay...	6.48	0.17	0.05	0.20	1.44	0.19	0.18
1914									
1	Timothy.....	Hay...	5.10	0.16	0.08	0.09	1.37	0.18	0.18
3	Timothy.....	Hay...	5.54	0.21	0.09	0.14	1.41	0.17	0.19
5	Timothy.....	Hay...	5.36	0.17	0.07	0.10	1.21	0.13	0.18
6	Grass........	Hay...	6.42	0.24	0.10	0.14	1.34	0.25	0.22
7	Timothy.....	Hay...	5.27	0.22	0.07	0.81	0.43	0.23	0.19
9	Timothy.....	Hay...	5.05	0.17	0.06	0.48	0.55	0.14	0.18
10	Grass........	Hay...	6.33	0.17	0.15	0.52	0.46	0.29	0.22
11	Timothy.....	Hay...	5.60	0.19	0.07	0.70	0.27	0.15	0.20
12	Timothy.....	Hay...	5.77	0.25	0.07	0.33	0.99	0.17	0.21

TABLE 10. ASH AND ASH CONSTITUENTS IN CROPS BY YEARS
(In pounds per acre)

Tank	Crop	Part of crop	Ash	Ca	Mg	Na	K	S	P
1910									
1	Maize........	Grain..	84.3	0.4	4.4	2.3	17.5	8.1	31.0
		Straw..	351.6	23.1	14.1	3.3	81.9	11.9	18.8
		Total..	435.9	23.5	18.5	5.6	99.4	20.0	49.8
3	Maize........	Grain..	99.0	0.8	5.8	2.8	23.1	9.2	42.0
		Straw..	430.1	26.2	13.4	6.4	105.4	12.2	14.1
		Total..	529.1	27.0	19.2	9.2	128.5	21.4	56.1
5	Maize........	Grain..	108.6	0.9	6.9	3.9	25.5	9.1	43.2
		Straw..	372.9	23.6	12.6	5.5	98.4	9.1	12.2
		Total..	481.5	24.5	19.5	9.4	123.9	18.2	55.4
6	Oats.........	Grain..	83.8	0.2	1.4	1.0	13.0	3.5	16.9
		Straw..	339.3	16.4	6.8	18.1	92.0	9.5	8.5
		Total..	423.1	16.6	8.2	19.1	105.0	13.0	25.4
7	Maize........	Grain..	93.9	0.9	6.0	3.3	21.5	10.4	38.5
		Straw..	390.2	26.4	13.3	5.9	102.5	5.7	15.3
		Total..	484.1	27.3	19.3	9.2	124.0	16.1	53.8
9	Maize........	Grain..	102.1	0.7	7.0	3.2	22.7	7.6	40.5
		Straw..	370.2	24.2	11.9	4.2	95.6	5.5	13.6
		Total..	472.3	24.9	18.9	7.4	118.3	13.1	54.1
10	Oats.........	Grain..	93.1	0.2	2.0	1.5	15.4	5.2	20.5
		Straw..	363.3	17.0	6.8	19.4	92.6	7.7	9.3
		Total..	456.4	17.2	8.8	20.9	108.0	12.9	29.8
11	Maize........	Grain..	77.4	0.3	4.7	2.3	17.5	8.8	30.7
		Straw..	388.7	23.8	12.4	3.6	107.9	5.8	15.3
		Total..	466.1	24.1	17.1	5.9	125.4	14.6	46.0
12	Maize........	Grain..	86.6	0.3	5.9	2.7	20.0	8.8	36.1
		Straw..	355.4	23.6	12.4	3.7	98.2	6.9	15.1
		Total.	442.0	24.0	18.3	6.4	118.2	15.7	51.2
1911									
1	Oats.........	Grain..	116.0	3.1	3.8	5.7	13.8	6.0	10.3
		Straw..	327.3	13.7	5.7	13.5	106.6	9.0	10.6
		Total..	443.3	16.8	9.5	19.2	120.4	15.0	20.9
3	Oats.........	Grain..	108.6	2.4	3.3	1.5	14.7	4.9	8.7
		Straw..	243.1	9.7	3.5	7.9	82.4	5.8	8.3
		Total..	351.7	12.1	6.8	9.4	97.1	10.7	17.0
5	Oats.........	Grain..	88.5	1.8	2.6	1.2	11.5	4.4	7.3
		Straw..	201.1	8.5	3.7	6.6	67.9	6.0	11.0
		Total..	289.6	10.3	6.3	7.8	79.4	10.4	18.3
6	Grass........	Hay...	192.3	6.2	3.3	9.3	43.6	6.8	15.7
7	Oats.........	Grain..	103.5	2.4	3.2	1.3	13.6	5.4	8.6
		Straw..	222.3	10.8	4.1	7.1	74.0	6.7	12.3
		Total..	325.8	13.2	7.3	8.4	87.6	12.1	20.9
9	Oats.........	Grain..	111.0	2.5	3.3	1.5	15.2	5.4	8.8
		Straw..	242.8	9.2	3.4	5.7	84.8	5.4	12.3
		Total..	353.8	11.7	6.7	7.2	100.0	10.8	21.1
10	Grass........	Hay...	195.7	7.3	3.7	10.6	44.0	7.6	15.2

TABLE 10 (*concluded*)

Tank	Crop	Part of crop	Ash	Ca	Mg	Na	K	S	P
1911									
11	Oats.........	Grain..	105.5	2.0	2.7	0.6	13.6	4.4	8.4
		Straw..	238.6	7.8	3.1	6.5	72.9	5.9	10.9
		Total..	344.1	9.8	5.8	7.1	86.5	10.3	19.3
12	Oats.........	Grain..	106.0	2.1	2.5	0.9	13.3	4.6	8.1
		Straw..	271.6	10.6	4.4	7.1	86.8	7.8	13.1
		Total..	377.6	12.7	6.9	8.0	100.1	12.4	21.2
1912									
1	Wheat.......	Hay...	156.5	3.5	1.6	1.5	51.0	5.5	4.6
	Second growth	Hay...	150.5	3.3	1.8	2.3	28.4	4.8	4.2
3	Wheat.......	Hay...	143.8	2.6	1.2	1.4	48.0	4.6	5.1
	Second growth	Hay...	55.5	0.5	0.4	0.2	9.9	2.0	2.5
5	Wheat.......	Hay...	161.4	2.3	1.0	2.8	45.0	4.9	6.2
	Second growth	Hay...	32.7	0.7	0.4	0.8	10.5	2.0	2.4
6	Grass........	Hay...	195.4	7.3	2.9	3.9	40.2	6.7	5.0
7	Wheat.......	Hay...	122.8	1.7	0.8	2.1	38.2	3.7	4.9
	Second growth	Hay...	99.1	1.3	0.9	1.3	16.7	2.7	3.5
9	Wheat.......	Hay...	34.6	0.8	0.4	0.7	10.1	1.0	1.4
	Second growth	Hay...	156.9	4.3	2.0	1.6	28.0	4.2	4.5
10	Grass........	Hay...	177.5	7.8	2.8	3.5	42.5	6.5	4.2
11	Wheat.......	Hay...	30.4	0.9	0.4	0.9	9.0	1.0	1.2
	Second growth	Hay...	138.8	3.2	1.5	3.5	27.6	5.2	4.1
12	Wheat.......	Hay...	143.3	3.1	1.4	0.9	44.7	4.2	5.3
	Second growth	Hay...	28.2	0.5	0.4	0.9	8.0	2.1	1.9
1913									
1	Timothy.....	Hay...	325.8	14.4	4.6	14.7	71.2	10.9	9.6
3	Timothy.....	Hay...	381.6	12.2	4.2	19.2	80.3	9.6	12.3
5	Timothy.....	Hay...	271.6	9.1	3.4	8.6	74.2	6.8	9.6
	Clover.......	Hay...	148 2	27.9	6.0	3.7	28.9	2.7	2.7
6	Grass........	Hay...	359.4	9.1	4.0	9.3	45.9	10.4	8.5
7	Timothy.....	Hay...	312.9	9.1	2.9	9.1	67.4	10.7	8.6
9	Timothy.....	Hay...	277.5	5.9	2.3	8.7	73.0	6.0	8.8
	Clover.......	Hay...	162.0	30.6	5.1	4.4	34.9	3.2	3.2
10	Grass........	Hay...	343.5	10.1	2.6	8.4	36.9	11.6	8.0
11	Timothy.....	Hay...	274.7	7.1	2.0	8.6	61.5	7.8	7.9
12	Timothy.....	Hay...	293.3	7.9	2.1	8.9	64.9	9.0	8.2
1914									
1	Timothy.....	Hay...	257.9	8.0	4.1	4.7	69.3	9.1	9.3
3	Timothy.....	Hay...	282.1	10.6	4.6	7.1	72.0	8.9	9.8
5	Timothy.....	Hay...	300.3	9.5	4.1	5.7	67.6	7.6	10.2
6	Grass........	Hay...	261.2	9.6	4.0	5.9	54.4	10.3	9.1
7	Timothy.....	Hay...	222.7	9.2	3.1	34.1	18.1	9.8	8.1
9	Timothy.....	Hay...	301.4	9.9	3.6	28.9	32.4	8.2	10.7
10	Grass........	Hay...	207.3	5.7	4.9	17.2	14.8	9.4	7.2
11	Timothy.....	Hay...	179.3	6.1	2.1	22.4	8.8	4.9	6.5
12	Timothy.....	Hay...	218.3	9.3	2.9	12.4	37.4	6.4	8.0

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CORNELL UNIVERSITY
AGRICULTURAL EXPERIMENT STATION

HEREDITY STUDIES IN THE MORNING-GLORY (IPOMOEA PURPUREA [L.] ROTH)

ELMER EUGENE BARKER

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HEREDITY STUDIES IN THE MORNING-GLORY (IPOMOEA PURPUREA [L.] ROTH)[1]

ELMER EUGENE BARKER

It is attempted in this paper to give the results obtained in researches on the genetics of certain characters in the common morning-glory (*Ipomoea purpurea* [L.] Roth), and to demonstrate the mendelian behavior of certain genes postulated to explain them. The characters here studied are color of the seed coat, and feathering, color, and flaking of the corolla.

The morning-glory is a plant well suited for work in experimental genetics. Its flowers present a large series of color types; it is vigorous, and very resistant to adverse conditions of all sorts; it is self-fertile and bears many seeds on every plant; it is very resistant to most insect attacks and fungous diseases; it can be grown in the greenhouse as well as out of doors if the temperature is warm enough.

METHODS USED IN STUDY

The stock used was the common variety of morning-glory. At the beginning of the investigation some Japanese morning-glories were grown, but they proved to be tender under the very cool conditions that prevailed in the house where they were planted, and no crosses were obtained, either between the two kinds or between the Japanese varieties themselves.

If the house is cool or the light is insufficient (as during winter months at Ithaca), the plants will not vine and will bloom as soon as one or two pairs of true leaves have unfolded. If the temperature is warm and humid, or under optimum garden conditions, the vines become very large and do not bloom until late. In these experiments a convenient medium was struck by growing the plants in small pots, whereby they could be kept at small size but still large enough to produce plenty of flowers.

At first the seeds were sown in the small pots, one to a pot, and the pots were plunged into the soil or ashes of the greenhouse bench or of the garden. It was found better to germinate the seeds between damp blotters in a germinator and then to plant the young seedlings. In the spring of 1915 an attempt to germinate the seeds in damp cotton proved disastrous, because they smothered and more than half of the cultures were thus lost. Some of the seeds have integuments so impervious to moisture that germination is very slow under natural conditions. It can be hastened by cutting a small hole thru the seed coat to allow the water to enter. In 1916 seeds were successfully germinated in petri dishes on damp filter paper, and the seedlings were then put directly into the soil of the garden.

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[1] Paper No. 60, Department of Plant Breeding, Cornell University, Ithaca, New York.

Early frosts at the end of two seasons killed the cultures before complete notes had been taken, so that only very meager data were obtained on most of the pedigrees and in many instances no seeds were produced for carrying certain pedigrees further. In the summers of 1915 and 1916 the plants in the garden were so late that no crossing was attempted. Some of these plants were cut back severely and removed to the greenhouse, where crosses were later made with them.

The stigma is receptive for pollination on the same morning that the flower opens. Pollination must be done early, as the flowers wither very soon, especially on hot days. Emasculation can be performed as late as the afternoon previous to the day of the flower's opening. The flowers are so readily self-fertile that when selfing was desired in these experiments it was found sufficient to tie the tip of the mature bud with a bit of cotton thread and leave it alone, or else to shake and pinch the corolla a little the next morning in order to insure the pollen's reaching the stigma. Except in the warmer months, however, when the ventilators and doors of the houses were open, or when the plants grew in the garden, this precaution was not necessary. No trouble was given by insects interfering with the pollinations. In the garden all pollinations were guarded by bagging.

In the winter of 1912-13, 488 cross- and self-pollinations were made in the greenhouse, of which 55 per cent set seed. In the summer of 1912, between August 14 and September 1 over 600 pollinations were made in the garden, of which 51 per cent of the self-pollinations and 35 per cent of the cross-pollinations set seed.

The colors of the flowers were at first described and recorded by means of the *Répertoire de Couleurs.*[2] Later it was found more convenient and more nearly accurate to compare each flower with a colored sketch and refer it to a certain type. The light purple type varies from approximately dark blue to dark purple. Dark purples on withering break down into light purple and magenta. Indeed, all the blue series are subject to such a change in withering; the blue pigment breaks down and the flower appears transformed into one of the red series. Thus, in cool, cloudy weather flowers may remain open for two days, blues on the second day appearing as red. On cool mornings in early autumn the pigments do not develop properly, and it was found necessary at such times to give up all attempts to classify the types. Records were always checked at least once when possible, and often many times.

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[2] See under *Société Française des Chrysanthémistes et René Oberthür*, in *References cited*, page 38.

The classification into types is in many cases rather arbitrary. The pinks verge into pale mauve, and dark mauves are about the same as lighter magentas. In the same way, dark blue is very like some of the hybrid light purples, while other hybrids of this type are hardly less intense in color than typical homozygous dark purples.

HEREDITY OF COLOR OF SEED COAT

The seed coats of the morning-glory plants studied were of two colors—black and a light yellowish brown, or tan. These two colors were found to be inherited in an alternative and exclusive manner as a simple mendelian allelomorphic pair of characters. Black was dominant over tan.

Since the integuments of a seed are part of the maternal (P_1) somatic tissues, seeds borne on plants that are either duplex or simplex for black will in either case be black-coated. Only a pure recessive plant can bear tan-coated seeds. However, a tan-coated seed can contain a simplex embryo, resulting from the fecundation of the recessive ovule by a dominant germ. A black-coated seed can contain a duplex or a simplex dominant embryo, or even a double recessive embryo. The embryo always represents, of course, a different generation from the seed coat that contains it.

TABLE I. DATA OF COLOR OF SEED COATS IN HYBRID PEDIGREES OF PURE RECESSIVES*

Pedigree no.	Color of seed coats of P_3	Color of seed coats of P_2	Color of seed coats of female parent	Color of seed coats of male parent	Number of progeny and color of their seed coats			
					F_1	F_2	F_3	F_4
109......	b	b	b	b	4 b	18 b	111 b	34 b
118–5....	......	......	B†	b	1 b	3	9 b	....
132......	b	b	b	b	3 b	30 b	......	....
143......	b	b	b	b	6 b	......	......	....
151......	b	b	b	b	6 b	3 b	......	....
152......	b	b	b	b	6 b	4 b	......	....
230......	b	b	b	b	2 b	38 b	......	....
108......	b	b	b	b	3 b	22 b	......	....

* The dominant character black is symbolized by *B*, the recessive tan by *b*.

† The seed parent in cross 118 bore black-coated seeds and several of the F_1 sibs to no. 5 were black-coated. No. 118–5 itself, however, was a pure extracted recessive.

The color of seed coats in hybrid pedigrees of pure recessives is shown in table 1. The following system was used for numbering the plants: Each progenitor of a pedigree was given a number below 100; crosses were designated by numbers in the hundreds, a different set of hundreds being used for each year. Individual offspring from a self-fertilized plant were designated by consecutive numbers separated from the number of the parent plant by a dash. The number of dashes in the pedigree number gave, therefore, a clue to the number of generations that the pedigree had been self-fertilized. Thus, the first plant in a lot of seed was numbered 15–1, the second 15–2, and so on. When a plant was selfed, its progeny were numbered 15–2–1, 15–2–2, and so on. The F_1 plants from a cross would be numbered 100–1, 100–2, and so on, or 230–1, 230–2, and so on.

It may be assumed from the behavior of such pedigrees as those shown in table 1 that a pure recessive plant when self-fertilized will produce only tan-coated seeds thruout any subsequent number of generations in which the progeny also are self-fertilized. No black-coated seeds were ever produced in any of these pedigrees.

If black-seeded plants are homozygous, then, when they are self-fertilized, succeeding generations will produce indefinitely black-coated seeds, as is shown in four pedigrees in which the seed coats of the first and second parental and the first filial generations, as well as the plants under consideration, were all black. Here is evidence that the character bred true thru four generations.

Black-coated heterozygous seeds, however, will give rise to plants the integuments of whose ovules will all be black but whose eggs contain either the dominant or the recessive gene. When self-fertilized, these plants will produce seeds that are either duplex or simplex dominants or pure recessives.

This hypothesis is supported by the data of pedigrees 100 and 200. In both cases the seed parent of the cross came from recessive stock and the pollen parent from black-coated stock. In both cases all the F_1 plants bore black-coated seeds. In pedigree 100 the F_2 progeny from one of these black-seeded plants when selfed consisted of 10 blacks and 1 tan. In pedigree 200 the F_2 progeny from one plant consisted of: 1 tan which when selfed gave rise to 25 tans — pure extracted recessives; 1 black which gave rise to 4 blacks; and 1 black which gave rise to 17 blacks and 6 tans. In cross 102 the seed parent was a recessive and the pollen parent was black-coated, but the latter was evidently simplex for the dominant character because the F_1 plants were both black-seeded and tan-seeded, there being 2 blacks and 1 tan.

THE GENETICS OF THE FEATHERED COROLLA

The character here termed *feathered* is a sort of ragged condition that occurs on the outside of the corolla. Narrow strips and filaments arise about the base of the corolla tube and on its outer surface, fringing it about and giving it a bizarre feathered appearance.

The origin of this character in the writer's cultures was a single plant out of ten that came from commercial seeds in a packet marked *Double*

Flowering. None of the others were ragged. The flowers were white, and, altho the rays were plain white while the plant was growing in the weak light of the greenhouse during the winter, later in the season a lavender spot developed on each. This spot appeared also in the progeny.

This plant, no. 5–2, was used in six crosses, with plants of various colors. The raggedness appeared in the F_1 colored hybrids. Only 12 plants came to bloom in these six pedigrees. Of these, 7 were ragged and 5 were smooth. The indication is, then, that the plant no. 5–2 was simplex for the gene causing this character, and that the character is a dominant one. The data for F_2 and F_3 generations regarding this character are very meager, but the indication again is that the smooth or recessive plants breed true to lack of the character.

This character was transferred from the original white plant to various plants of the color types by crossing.

PIGMENT COLORS IN PLANTS

There are two classes of coloring substances in plants: (1) organized color principles, which are characterized by being an organic part of the plastid body and are always associated with specialized protoplasmic bodies, the chromoplastids; and (2) unorganized color principles, which are not a fundamental or organic part of the plastids, but are pigments dissolved in the cell sap and seated in the vacuoles of the cells. In flowers the latter are almost always confined to the epidermal cells, but when found in leaves, fruits, and other organs they are situated as often as not in deeper-lying tissues.

According to the modern theory of the formation of these cell-sap pigments, they are the result of enzymes in the nature of oxidases which act upon certain substances in the cells that are capable of oxidation, thereby producing pigments. The oxidase is supposed to be of a dual nature and to consist of two constituents, a peroxidase and a peroxide. The peroxide functions as an activator to the peroxidase in the sense that it supplies the latter with oxygen which may then be transferred to an oxidizable body. When all three substances are present, the peroxide, the peroxidase, and the oxidizable body, oxidation takes place and pigment is formed which gives color to the organ.

Tests by various workers on many different species of plants show that the distribution of oxidases coincides with that of the anthocyanic pigments, and it has been pointed out by Miss Wheldale (1910, 1911)[3] and by Clark (1911) that peroxidase is more widely distributed than the organic peroxide that activates it.

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[3] Dates in parenthesis refer to *References cited*, page 38.

Experimental tests of both a chemical and a genetical nature have demonstrated that most whites are due to the absence of some part of the mechanical device for the formation of pigment and are recessive to the pigmented forms when crossed with them.

Some plants show by their genetical behavior that either of two factors in pigment formation — chromogen or oxidase — may be lacking from a variety. It is possible, for example, in such plants as sweet peas, stock, and lychnis, by mating certain white-flowered individuals, or in the aleurone of maize by crossing two white-seeded strains, to bring together the two complementary factors and thus produce a reversionary, colored F_1 generation.

In the case of the so-called "dominant whites" the lack of color is supposed to be due to an inhibitor which prevents the formation of the pigment altho all the necessary substances for its formation may be present. The action of the inhibitor may be complete, as in the dominant whites, or it may be only partial, resulting in dilute colors — as in stocks, where it is supposed to be responsible for the dilute varieties of rose, flesh, and other pale colors. The factor in these cases is supposed to be of a limiting nature and to prevent entire reaction.

In some cases the inhibiting factor appears to be of such a nature that it acts locally, resulting in parti-colored "flaked" forms, or in various color patterns, or in the dominance of what appears to be a lower grade of pigmentation over a higher grade. In many cases the inhibition is not quite complete, and dominant whites are often distinguishable by the presence of patches or washes of color not found in the recessive whites (Shull, 1912 : 121). In *Papavar Rhoeas* the presence of a white margin on the petals is dominant over its absence. It is probable, therefore, that the white margin is due to the presence of an inhibitor localized in the margin of the petals (Shull, 1912 : 128). There is also an inhibitor which affects the body of the petals, producing what is essentially a dominant white, tho the inhibition is often very imperfect, in which case the flowers are more or less washed and striated with color but generally whitish (Shull, 1912 : 134).

Miss Marryat (1909 : 45) reports that in her experiments with *Mirabilis jalapa*, flaking proved dominant thruout; and Correns (1910 : 424) confirms her results. In the writer's experiments with morning-glories the same condition has been found to obtain. The distribution and behavior of color in such cases as these would seem to indicate a localization of the color-producing substances rather than the presence of an inhibitor.

The chemical substances that react together to form anthocyanic pigments can be interpreted in mendelian terms if it is considered that the mendelian factors involved in the various stages of color production are in the nature of enzymes, oxidases, and chromogens. Their activities are in many cases interdependent. Thus, for instance, red anthocyan may be regarded as a highly oxidized and colored product of an oxidase acting upon a colorless chromogen; this oxidase, therefore, is equivalent to the "reddening factor" of the mendelists. Similarly, a second oxidase, the mendelian "bluing factor," leads to the formation of purple anthocyan from the product of the action of the reddening oxidase (red anthocyan). But the bluing oxidase is unable to form pigment directly without the process of the reddening oxidase. If the power to form the bluing oxidase is lost from the purple type, a red variety is the result; if the reddening factor is lost, an albino results, which may still contain the ferment capacity for the bluing action.

In this way can be represented, in terms of mendelian genes and in terms of oxidases, the series of genetically different varieties which actually exist, ranging as they do in such plants as stocks and morning-glories from pink thru mauves, magentas, and reds, or thru the blue series to the purple type. It is evident that the loss of either element, peroxide or peroxidase, will give rise to albinism, even tho the plant may still carry the bluing factor or other modifying genes. Hence in any species having a complex series of color varieties there are a number of possible albinos, both genotypically and physiologically different from one another. The colors of varieties arising from an anthocyanic type may be regarded as components of the original anthocyan of the wild ancestral prototype. Conversely, the type may be supposed to have lost its components in succession, thus giving rise to a series of color variations.

This chromogen-oxidase theory of the formation of anthocyanic colors furnishes an explanation for the behavior of the color types of the morning-glories here studied. Their genetical behavior is considered in the next section, where it is shown that these color types form an epistatic series, each step of which is determined by the active presence of a particular gene or complex of genes which are probably in the nature of enzymes.

THE GENETICS OF COLOR TYPES

In accord with the enzyme-chromogen hypothesis of the formation of floral pigments, the following symbols and formulas are here used as working hypotheses to account for the genetic relationships of the various color types of morning-glories used in the present study:

Symbols

C = Chromogen
R = Oxidase acting on C
B = Bluing gene
X = Peroxidase or intensifier acting on C and R, and on B
I = A further intensifying gene

Formulas

Magenta	Light blue	Dark blue	Light purple	Dark purple
CCRRXXII	CCRRBB	CCRRBBXX	CCRRBbXxIi	CCRRBbXXII
CCRrXXII (or dark mauve)	CCRrBbXx	CCRrBBXX		CCRRBbXXIi
CCRrXXIi (or mauve)	CCRrBbXX	CCRRBbXX		
	CCRRBbXx	CCRRBBXx		
	CCRrBBXx			
	CCRrBBxx			

White	Tinged white	Pink	Mauve
CcRRBB	CCRrBb (or pale blue)	CCRR	CCRRXX
CcRrBBXX	CCRr	CCRRxx	CCRRbbXX
CCrrXX	CCRrXx		CCRRbbXx
CCrrXx	CCRrXX		CCRRbbXXii
CCrrxx	CCRrxx		CCRrXxIi
CCrrBBXX	CCRrbbXx		CCRRII
CCrrBbXx			CCRRXx
and all other plants lacking C or R or with C simplex			CCRRXxbbii
			CCRrXxII

The evidence in support of these hypothetical formulas is derived in two ways from a germinal analysis — by means of (1) selfing, and (2) hybridization. The evidence is considered separately under these two headings.

BEHAVIOR OF COLOR TYPES WHEN SELF-FERTILIZED

Type 1 *White* (Plate II)

Description of the type.— The white type is a pure white and a true albino. The star-shaped rays in the corolla may in some cases be slightly yellowish, but so pale as to be hardly different from the ground color. In other cases they may be flushed with pink or may have a definite spot of lavender.

The albino type can be accounted for hypothetically by the absence of sufficient chromogen to form any anthocyanic pigments (cc or Cc) or by the lack of sufficient oxidase (R) to react with C and form anthocyan, without which combination the other genes cannot act even tho they may be present. Thus any formula lacking either C or R, or even one having C in a simplex condition, might represent a white.

Theoretical consideration of data.— Thirty-three white plants were selfed and yielded an aggregate progeny of 262 whites. No colored types appeared. Chemical tests on some of the white flowers seemed to indicate the presence of both peroxide and peroxidase in the tissues of the corolla, but a lack of chromogen. Certain it is that these plants lacked some essential part of the mechanical device for the production of pigment — either C or R, or both. The presence or absence of other genes could be determined only by cross-breeding.

Other whites threw colors when selfed as shown in table 2:

TABLE 2. WHITES SELFED WHICH THREW COLORS

Pedigree no.	Dark blue	Light blue	Mauve	Pink	Tinged white	White
108–5–1	1	....	....	....	....	....
109–2–7	....	....	....	3	7	40
109–5–10	....	....	....	....	3	....
132–2–1	....	....	....	5	....	....
152–3	....	1	....	....	....	4
152–6	....	....	....	1	1	1
155–2	12	1	....	....	....	....

Plants 109–5–10 and 132–2–1 were doubtless tinged whites that were recorded as true whites. They had sibs that were recognized as tinged whites. Plant 108–5–1 could give a dark blue because it was heterozygous for both the genes C and R (CcRrBBXX). If more progeny had been obtained from it one would have expected also magentas, mauves, pinks, and whites. Plants 109–2–7 and 109–5–10, if of the constitution CCRr, could throw pinks, tinged whites, and whites when selfed.

Plants 152–3 and 152–6 were two white sibs among the F_1 progeny of a cross between a light blue and a white. The other sibs were four light blues. Their pedigree affords an interesting example of the release of hidden factors thru mendelian recombination. It is given in table 3, with the putative formulas of the parents:

TABLE 3. PEDIGREE NO. 152

P_1	Plant no.	F_1	F_2
		Color	Actual number
18–8–1 light blue	1	Light blue	6 dark blue 12 light blue 5 tinged white 4 white
CCRRBB	2	Light blue	....
× CcRRBB	3	White	1 light blue 4 white
21–5–2 white	4	Light blue	2 dark blue 9 light blue 2 pink 1 tinged white 9 white
	5	Light blue	....
	6	White	1 pink 1 tinged white 1 white

The intensifying gene X also was probably brought into the cross by one of the parents in simplex condition, thus allowing the dark blues to appear in F_2.

Type 2 *Tinged white*

Description of the type.— The tinged white type differs from the true white, or albino, in often showing, when the plant is vigorous and growing in strong light, a very faint flush of pink in the solid ground between the rays of the star, the flush becoming deeper on the rays themselves. When conditions are not favorable it appears as a plain white, and might then be easily mistaken for and recorded as that type.

Theoretical consideration of data.— The tinged whites when selfed threw colors as shown in table 4. Plant 100–1–11–1 was recorded once as mauve but was not checked. Plant 108–1–5 was probably like 108–5–1 in constitution. The latter has already been discussed among the whites. Plant 109–5–10, recorded as white, was probably a tinged white like its sib 9, which "faded to pale pink." Plant 132–2–1, recorded as white and already discussed, was probably a tinged white like its sib 11. Plant 159–2, recorded as "tinged white or very light blue," was probably a light blue in constitution but phenotypically a tinged white.

TABLE 4. TINGED WHITES SELFED

Pedigree no.	Dark blue	Light blue	Mauve	Pink	Tinged white	White
100–1–11	....	....	1	....	....	....
108–1–5	1	....	....	....	....	....
108–5–1	1	....	....	....	....	....
109–5–10	....	....	....	....	3	....
132–2–1	....	....	....	5	....	....
132–2–11	....	....	....	8	....	....
109–1	....	....	....	....	....	3
109–2	....	....	....	1	1	5
109–3	....	....	....	3	1	13
109–5	....	....	....	....	....	7
159–2	....	3	....	....	1	9
200–2–6	....	....	6	2	10	6

In pedigree 109 the F_1 plants were probably all truly tinged whites and of the constitution CCRr. The parents were a pink and a (doubtful) white. Such F_1 plants should throw pinks, tinged whites, and whites in the ratio of 1 : 2 : 1 when selfed. Altho the number of F_2 plants obtained was very meager (only 34), they are very far from showing agreement with this ratio, the colors being as follows:

	Theoretical	Observed
Pink	8.5	4
Tinged white	17.0	2
White	8.5	28

It is possible that some of the genetically tinged whites were classed as true whites.

In pedigree 200, arising from a cross between a light blue and a magenta, the F_1 plants were light purple. Plants grouped in this type vary greatly in color and are usually heterozygous for several factors. If when selfing a light purple plant the genes B and I were lost in the recombinations, then pinks and mauves would result. If R also were simplex in such a light purple F_1 plant, there would be a possibility that pinks and tinged whites might appear. Such seems to have been the case in this pedigree, where the second-generation plant 200–2–6, a tinged white, was selfed and gave a progeny consisting of 6 mauves, 2 pinks, 10 tinged whites, and 6 whites. The F_1 parent plant probably carried the genes X, B, and I in simplex condition, and they became lost out of the recombination that gave rise to plant 200–2–6. If this plant had been of the constitution CCRrXx, its behavior as described above could be explained, for then it could have given, when selfed,

CCRRXX	mauve
CCRRXx	mauve
CCRRxx	pink
CCRrXX	tinged white
CCRrXx	tinged white
CCRrxx	tinged white
CCrrXX	white
CCrrXx	white
CCrrxx	white

All the phenotypes here given were actually represented in the F_2 progeny of this individual.

The genetic behavior of tinged whites may be explained on the hypothesis of a formula CCRr. When selfed, then, they should throw pinks, tinged whites, and whites. Such was here found to be the case, in general, when the tinged whites were selfed, with the exceptions of the cases discussed above.

Type 3 *Pink* (Plate I)

Description of the type.— The type called *pink* is a very pale rose and somewhat lighter than the type here called *mauve.* It may be either paler or slightly more intense, factors such as water supply, vigor of the plant, amount of light, and so on, seeming to affect its intensity. It is paler and less blue than mauve, type 4.

Theoretical consideration of data.— If the chemical theory of color production as explained on page 9 is adopted, the pink type must be considered as the lowest in the series of color varieties of the morning-glory, hypostatic to all the others, and due to the addition to the white genotype of some one or more genes essential to the formation of anthocyanic pigment. If the full pink is supposed to be due to a double portion of the same gene (that is, a duplex condition) that causes the pink flush of the tinged white type, the pink type may be formulated as CCRR. This type, being homozygous, could then give only pinks when selfed.

Fourteen pink plants were selfed and in a progeny of 127 plants only pinks were found. It is a true-breeding type, as the hypothesis stated above demands.

Plant 211–1 was recorded as pink and checked as such. When selfed it threw 3 magentas, 3 mauves, 8 pinks, 1 tinged white, and 12 whites. It must have been a mauve (genotypically) with the formula CCRrXxII, which could throw all these types when selfed. Mauve could very easily have been mistaken for pink and recorded as such.

Type 4 *Mauve* (Plate I)

Description of the type.— The type called *mauve* is slightly darker and bluer than that called *pink.* The two are often so nearly alike that it is difficult to be certain to which type a flower belongs. This may, no doubt, have given rise to some experimental errors in recording the type, as in the case of plant 211–1, discussed above.

Theoretical consideration of data.— The data showing the behavior of mauves when selfed is very meager. Five plants were selfed and yielded an aggregate progeny of 80 plants, of which 61 were mauve and 19 were pink. The largest pedigree contained 59 plants, of which 42 were mauve and 17 were pink. Other plants threw only pinks, but the numbers were very small. The significant fact here, however, is that no types other than mauve and pink were thrown.

The mauve type may be considered as the pink genotype plus an added gene X which reacts with R to give a deeper and bluer hue. If a mauve plant were of the genotypic constitution CCRRXX, it should breed true; if simplex for X, it should throw three-fourths mauves and one-fourth pinks but no other types. This seems a plausible explanation of the data given above. Some of these plants may have been either simplex or duplex for X, since the numbers of their progeny were too small to demonstrate which was the case.

Type 5 *Magenta* (Plate I)

Description of the type.— The type called *magenta* is very similar to the mauve type, but the color is deeper, richer, and more intense. It is a brilliant color and does not change when the flower withers. It occurs also in a striped or flaked pattern on a white background, as discussed under a later heading (page 27).

Theoretical consideration of data.—Twenty-three magenta plants were selfed and yielded an aggregate progeny of 108 plants, all of which were magentas. Twenty-one others were selfed and did not breed true. These are discussed separately.

Among the first group was one that threw 5 magentas and 1 mauve. This mauve plant was not checked, however, and may have been a minus fluctuation of the magenta type. Another plant that had originally been recorded as magenta threw 4 dark blues only. It may, indeed, have been a dark blue itself, and recorded after it had begun to wither.

The magenta color may be supposed to be due to an additional gene I, an intensifier which acts upon the full mauve and produces a deeper saturation of the same hue. Its genotypic formula, then, would be CCRRXXII, and such plants when selfed could throw only mauves — they would breed true, as in the above cases.

If a magenta were simplex for one or more of its genes, however, it would throw, when selfed, magentas, mauves, and pinks in the ratio of 9:3:4. The behavior of the other magentas that were selfed can be explained on this hypothesis. There were 21 such plants and they gave a progeny of 93 offspring, of which 60 were magentas, 19 were mauves, and 14 were pinks. No other types were thrown. The theoretical and the observed frequencies are here given:

	Theoretical	Observed
Magenta	52.3	60
Mauve	17.4	19
Pink	23.3	14
	93.0	93

Type 6 *Light blue* (Plate I)

Description of the type.— The type considered as *light blue* is, as its name implies, a pale tint of blue. It turns to pink on withering.

This type may be supposed to be due to the presence of a bluing gene, B, in addition to those present in the pink type, but to lack the gene I of the magenta type. The light blue type does not breed true, and all evidence indicates that it is heterozygous in one or more genes and thus comprises different genotypes. It is conceivable that a pure strain might be obtained which would breed true, but as yet no such plant has been found in the writer's cultures. Such a plant would necessarily be of the constitution CCRRBB.

Theoretical consideration of data.— Examination of all the data for all the light blue plants that were selfed shows that one group, comprising 21 plants, threw only dark blues, light blues, tinged whites, and whites. These plants must have been duplex for the gene B, as they threw no mauves nor pinks. The summation of data for this group is: dark blues, 45; light blues, 64; whites, 55. Eight of the whites were faintly flushed with color, and so were really tinged whites in the blue series. It is significant to note that in all the four pedigrees in which these tinged whites made their appearance there was a common ancestor, plant 21. The blue factor B was brought in by this strain, as was further shown by the evidence from collateral breeding.

Another group of light blue plants threw mauves and pinks as well as blues and whites when they were selfed. These plants, together with their parents and offspring, are given in table 5:

TABLE 5. LIGHT BLUES SELFED

Pedigree no.	Colors of parents	Dark blue	Light blue	Mauve	Pink	White
222-10..	Light blue × white flaked magenta	5	29	2	......	23 (1 tinged)
132-2.......	Pink × white	3	6	......	3	4
132-3.......		6	5	......	......	5
132-2-1.....		....	......	......	5	....
132-3-8.....		3	......	......	......	....
151-3.......	Tinged white × dark blue	4	......	1	......	....
151-4.......		3	1	1	......	4
151-6.......		3	7	1	......	4 (1 tinged)
220-2.......	Dark blue × white	....	2	......	1	....
220-5.......		1	1	......	......	2
231-3.........	Pink × light blue	10	......	1	1	....
232-3.........	Pink × light blue	1	......	1	......	....
		39	51	7	10	42
*200-2-4......	....	......	......	......	......	33

* 200-2-4 was recorded as light blue, but when selfed it gave 33 whites and no colors. It must have been a white itself.

If a light blue were simplex for B, then in the recombination of genes, due to selfing, mauves and pinks might appear, as in the cases shown in table 5, due to the dropping-out altogether of the gene B.

If the light blue were heterozygous for all three genes, B, R, and X, then there would result a great number of genotypes in the recombination of genes following self-fertilization. The phenotypes resulting would be dark blue, light blue, mauve, pink, tinged white, and white. Many of these genotypes would be very slightly different from others, and the suggestion is borne in on one that a small difference in the presence or the potency of a single enzymatic determiner may change the intensity of the color enough to throw the flower into a different phenotype. It is very possible that environmental conditions affecting the physiological condition of the plant may throw plants of the same genotypic constitution into different phenotypes.

The behavior of pedigree 132 (table 5) appears to indicate that the light blues considered here were heterozygous as to the genes R, B, and X. The expected types all appeared except mauve and tinged white, and considering the small number of individuals it is not surprising that these two types also were not represented. No other types appeared.

Also, in the pedigree from plant 222–10 (a plant recorded as light blue), there occur the types dark blue, light blue, mauve, tinged white, and white, all of which may come from a plant of the constitution CCRrBbXx. The F_1 plants in this pedigree consisted of this plant and 4 other light blues. When selfed, the others also threw dark blues, light blues, mauves, tinged whites, and whites.

Type 7 *Dark blue* (Plate I)

Description of the type.— The type called *dark blue* is a brilliant, almost electric blue. This type is explained as due to the presence of a gene B in either simplex or duplex condition, in addition to all the genes necessary for the mauve type.

Theoretical consideration of data.— The dark blue plants that were selfed fell into two classes, those that bred true and those that threw other types.

In the first group there were 17 plants, of which 9 were F_1 hybrids and threw 35 dark blues, and 8 were not hybrids and gave 38 dark blues.

Altho the number in any of these pedigrees is small individually and cannot be taken as conclusive that these plants were homozygous in all the genes that go to make the dark blue type, the evidence is strong that such was the case. Such plants, then, may be considered to be duplex for all the genes (CCRRBBXX).

Other dark blues when selfed broke up into dark blues, light blues, mauves, and pinks (and in one case a doubtful light purple). The data are from only 8 F_1 plants, and the total F_2 progeny numbers only 72. Their behavior, however, shows that these dark blues must have been simplex for the gene B, so that, when selfed, it could drop out from some of the recombinations giving rise to the mauves and the pinks.

Type 8 *Light purple* (Plate I)

Description of the type.— The type called *light purple* is not homogeneous, but is so variable as to be difficult of classification. Typically it is between dark purple and magenta. It may appear as a dark purple streaked or washed with magenta, or, when fresh, it may be clear and pure and little darker than a typical dark blue. It seems to be in a very unstable condition, and quickly changes to magenta on a warm day or as the flower begins to wither. Very often this color in a flower seems to indicate a hybrid condition of the plant that bears it.

Theoretical consideration of data.— Thirty-seven F_1 pedigree plants and 4 others from commercial seeds were classified as light purple, and when selfed gave an aggregate[4] progeny of 70 dark purples, 37 light purples, 36 dark blues, 17 magentas, 9 mauves, 1 pink, 6 light blues, 14 whites, 9 cream whites, and 3 tinged whites.

When the data of light purples selfed are examined in the aggregate it is seen that this is characteristically a heterozygous type. It breaks up into all the other types, including dark purple, which is higher in the color series. It does not breed true. An analysis of the type is impossible as a whole, but must be worked out in each individual case by analysis of progeny and by synthesis from other plants of known constitution.

Type 9 *Dark purple* (Plate I)

Description of the type.— The type considered as *dark purple* is a very rich pansy, or bluish purple, color. The dark purple type may be supposed to contain the intensifying gene I in addition to all the other genes of the other types.

Theoretical consideration of data.— The data for the dark purple plants that were selfed may be considered in two classes — those that bred true and produced only dark purples, and those that broke up and threw other types.

In the first group there were 9 plants, which gave an aggregate progeny of 54 plants. These were all dark purples; no other types appeared. It may be assumed, then, that these plants were duplex for all genes that concern the dark purple type (CCRRBBXXII). It is possible, however, that they may have been simplex for either X or I and still bred true.

Other dark purples split up in various ways when selfed and threw all the types lower in the scale. Such behavior is to be expected when the purples are heterozygous as to various genes. Three of these plants threw whites. This, too, is to be expected if R is simplex.

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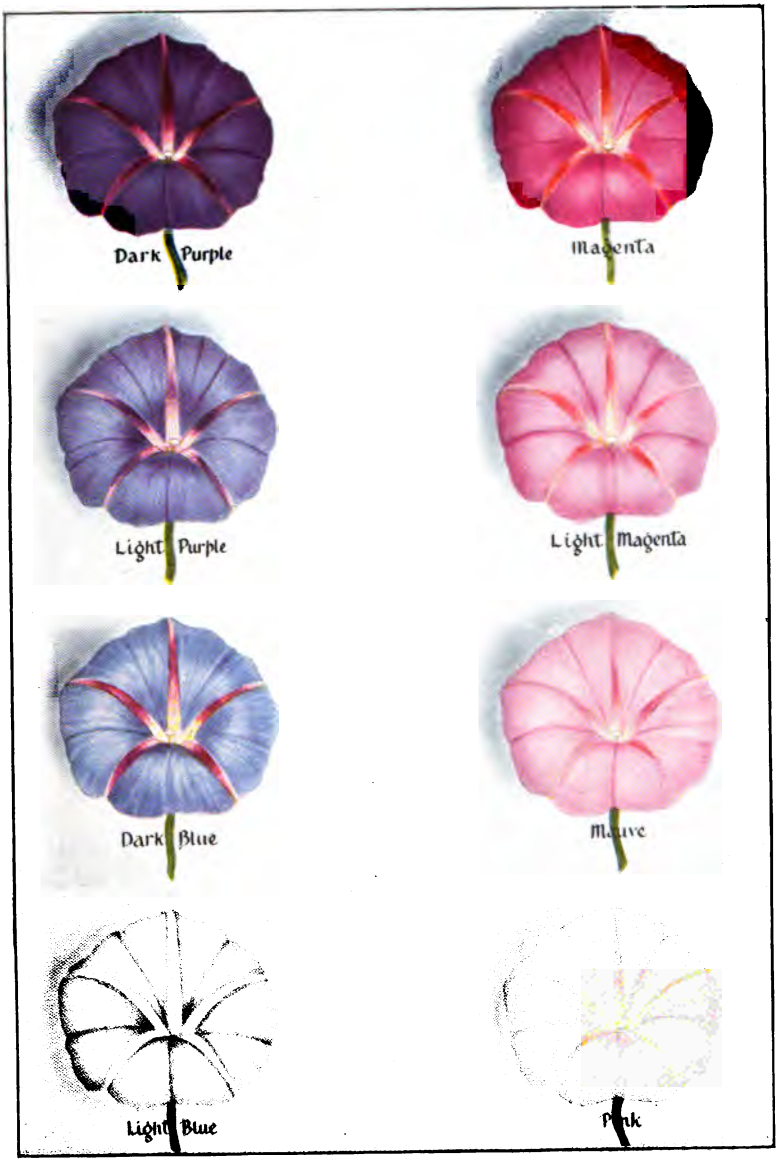
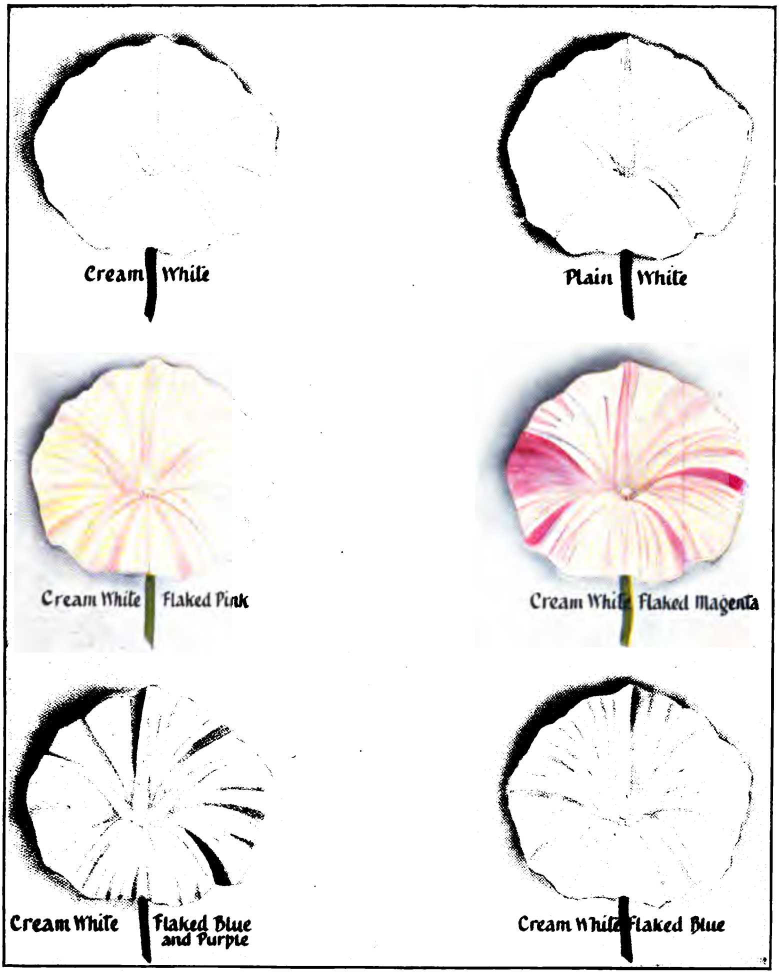
[4] The data are here considered in the aggregate because the progeny in any single case was too meager to be treated separately.



SOLID-COLOR TYPES

UNIV. OF MICH.



Cream White

Plain White

Cream White Flaked Pink

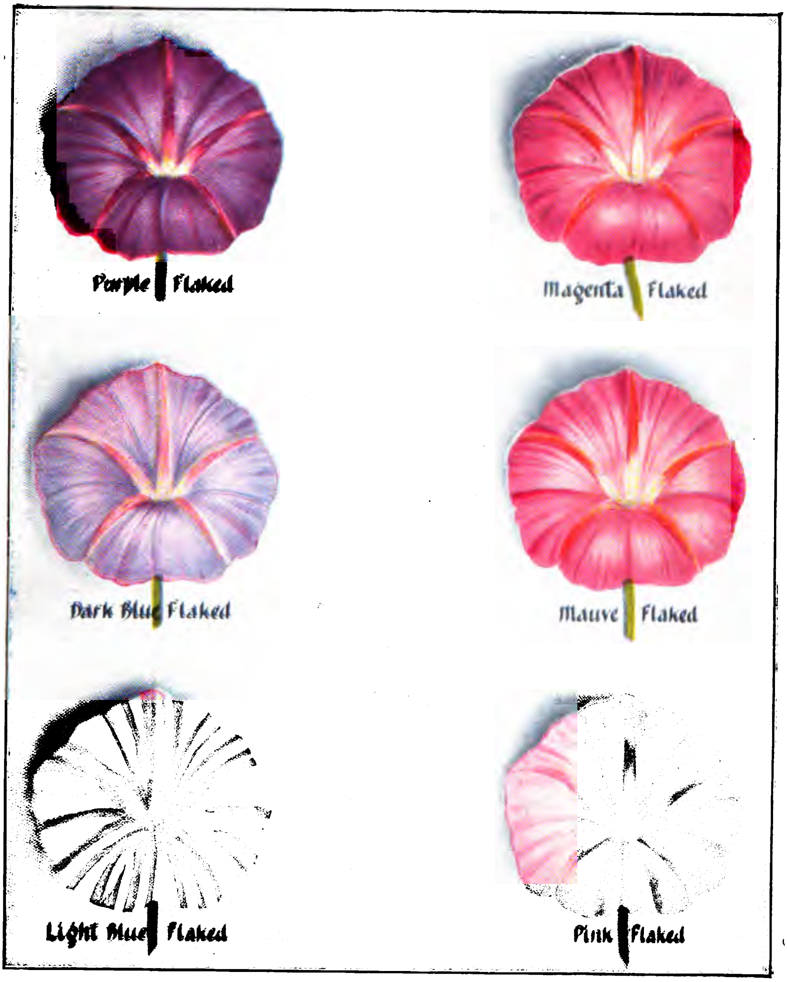
Cream White Flaked Magenta

Cream White Flaked Blue and Purple

Cream White Flaked Blue

WHITE TYPES, PLAIN AND FLAKED

UNIV. OF IOWA



FLAKED SOLID TYPES

BEHAVIOR OF COLOR TYPES IN CROSSES

Under this heading is considered the behavior of each type separately when crossed with the other types.

Type 1 *White* (Plate II)

White crossed with pink.— Two crosses are recorded between white and pink. Cross 132 has already been discussed (page 19). In the other cross, 169, the F_1 consisted of 2 whites and 1 light blue. This might be expected if a pink (CCRR) were crossed with a white that was simplex for both B and X (CCrrBbXx). Plant 169–3, the light blue (hypothetically CCRrBbXx), was selfed and gave 1 mauve and 1 white. If it had produced more offspring, light blues, mauves, pinks, tinged whites, and whites would all have been expected to make their appearance, due to the recombinations or dropping-out of these various simplex genes.

White crossed with mauve.— In cross 121 there were only two F_1 plants and both were mauves. This result might have been obtained if a mauve containing I (instead of X) were crossed with a white lacking both B and I and with or without X. Such a cross would give only mauves.

The F_1 of cross 108 consisted of 5 light blues, which split up into an F_2 of dark blues, light blues, and whites. Had larger numbers been obtained, the rarer genotypes for mauve and pink might have been expected to appear. This cross may be explained on the assumption that the white parent brought in the gene B. The F_1 plants, then, would be all light blues, and simplex for both R and B but either simplex or duplex for X.

The only other cross between a white and a mauve was cross 125. It gave 1 light blue and 1 light purple. The mauve parent, however, was recorded in the greenhouse during the first year of the experiment, when the author was not so familiar with behavior of types as he became later. It was probably a withered dark blue, because when selfed it threw 20 dark blues and no others. For this reason it is more probable that this parent brought in the gene B than that the white parent carried it.

White crossed with magenta.— Four crosses were made between white and magenta. In the F_1 from these crosses there appeared magentas, mauves, and pinks. The significant feature of this fact is that no types higher in the scale than magenta appeared, except in cross 209, in which case the white parent must have contained the gene B. It had light blue sibs out of a white parent selfed. It should be noted also that no tinged whites nor whites appeared, which is to be expected on the supposition that magenta contains both C and R in duplex condition.

In cross 129 the single F_1 plant obtained gave, when selfed, 3 whites and 1 mauve. This might occur if the white parent lacked only the gene

R but contained both X and I. The F_1 magenta, then (or dark mauve), would be of the constitution CCRrXXII or with I simplex. Such a plant could throw magentas, light magentas (or dark mauves), mauves, tinged whites, and whites.

White crossed with light blue.— The F_1 in cross 133 consisted of 2 light purples, and in cross 158 of 1 light purple. Light purples could result from a cross between white and light blue if the white parent brought in the gene I.

If the light blue parent is simplex for R, white as well as light blues will appear in the F_1, as was the case in crosses 116, 152, 154, 155, and 157.

White crossed with dark blue.— In cross 104 the F_1 consisted of 5 dark blues and the F_2 of 15 dark blues. Such a result might occur in a cross between white and dark blue if the white parent carried the genes B and X in duplex condition but lacked only R. One-third of the F_2 plants would be expected to be whites, as in the following schema:

$$\begin{array}{lll} & F_1 & F_2 \\ \text{CCRRBBXX dark blue} & & \\ \qquad\times & \text{CCRrBBXX dark blue} & \text{CC}\left\{\begin{array}{l}\text{RRBBXX dark blue}\\ \text{RrBBXX dark blue}\\ \text{rrBBXX white}\end{array}\right. \\ \text{CCrrBBXX white} & & \end{array}$$

If the white parent carries the gene I, light purples will constitute the F_1, as in cross 221. The light purple plant obtained from this cross gave 8 purples and 1 dark blue.

In cross 220 the F_1 consisted of 5 light blues, which gave an F_2 progeny of 1 dark blue, 1 light blue, 1 pink, and 2 whites. This might result from a cross in which both parents lacked the gene I.

White crossed with dark purple.— Only three crosses are recorded between white and dark purple. The offspring were all either dark purple or light purple. In F_2 they broke up into all the hypostatic types, as would be expected if many or all of the genes were simplex.

In cross 162 four of the dark purple F_1 plants that were selfed bred true, but the fifth threw purples, light purples, light blues, and whites.

Type 2 *Tinged white*

Tinged white crossed with light blue.— In cross 150 a light blue was mated with a tinged white. The F_1 plants consisted of 2 mauves. To make it possible for these mauves to appear, the blue parent must have been simplex for B, so that it dropped out in these F_1 combinations. If larger numbers had been obtained, light blues and tinged whites would also have been expected, but no true whites, since R would always be present at least in simplex condition.

Tinged white crossed with dark blue.— In cross 151 the F_1 progeny consisted of 2 dark blues and 4 light blues. In the next generation the two dark blues produced 9 dark blues and 2 mauves, while the light blues broke up into dark blues, light blues, mauves, tinged whites, and whites, as was to be expected. The tinged white parent must have carried the gene X, otherwise no dark blues could have appeared in the F_1. Such a cross may be represented as follows:

$$\begin{array}{c} \text{CCRRBBXX dark blue} \\ \\ \times \\ \\ \text{CCRrbbXx tinged white} \end{array} \qquad \text{CC}\left\{\begin{array}{l} \text{RRBb}\left\{\begin{array}{l}\text{XX dark blue}\\ \text{Xx light blue}\end{array}\right. \\ \\ \text{RrBb}\left\{\begin{array}{l}\text{XX light blue}\\ \text{Xx light blue}\end{array}\right. \end{array}\right.$$

In cross 159 the tinged white parent was a sib of the one used in cross 151. The two F_1 plants were recorded as "very pale blue or tinged white," showing that they contained the gene B and belonged to the light blue type rather than to the tinged white of the red series. This is further shown by their behavior when selfed. They gave 3 light blues, 1 tinged white, and 11 whites. None of the red series here made its appearance. Assuming a cross between a tinged white of the same constitution as the one used in cross 151 and a dark blue that is simplex for X, the F_1 would contain very pale blues of the constitution CCRrBb which would throw light blues, tinged whites, and whites, as in cross 159.

Type 3 *Pink* (Plate I)

Pink crossed with purple.— Since purple is due to several genes superposed upon the pink type, it might be expected to be epistatic to pink. So it was found to be in the two crosses recorded between pink and purple. The purple parents were sibs, as were also the pink parents. Cross 175 gave an F_1 progeny of 1 dark purple, while cross 176 gave 4 light purples, which were almost dark. The F_2 progeny from these crosses consisted of purple, dark blue, magenta, mauve, and pink types.

Such behavior is to be expected in a cross between a homozygous dark purple and a homozygous pink. The F_1 would consist of purples that would split up into all the hypostatic types except tinged white and white, these two types appearing only where R is simplex or nulliplex.

Type 4 *Mauve* (Plate I)

Mauve crossed with magenta.— Crosses 128, 203, 205, 206, and 208 were all made between magentas and pinks, and in every case the F_1 plants were all magentas. When selfed, these F_1 magentas gave an F_2 progeny comprising magentas, mauves, and pinks.

The absence of the gene B in either parent precluded, of course, the appearance of any of the blue series in any generation subsequent to the cross. The fact that the genes C and R were intact in both parental types, according to theory, precluded the appearance of tinged whites or plain whites. Magenta, bearing genes for greater intensification of color than mauve, would be dominant to it, as was found to be the case, and in the recombination of genes when F_1 plants were selfed, there would be produced such recombinations as would give rise to the three red types and to intervening gradations of color which are difficult to classify as either the one or the other.

Mauve crossed with light blue.— Four crosses were recorded between mauve and light blue. The F_1 offspring were dark blues, light blues, and mauves; the F_2 plants were dark blues, light blues, mauves, and pinks.

According to hypothesis, if a mauve is crossed with a blue the gene B will be brought into the zygotic combination of F_1, and, this being dominant to the genes of the red series, only blue could result. If the light blue parent were simplex for B, some mauves could appear in F_1 as follows:

$$\begin{array}{ccc} & & F_1 \\ \text{CCRRbbXX mauve} & & \\ \times & \text{CCRR} & \left\{\begin{array}{l} \text{Bb}\left\{\begin{array}{l}\text{XX dark blue}\\ \text{Xx light blue}\end{array}\right. \\ \\ \text{bb}\left\{\begin{array}{l}\text{XX mauve}\\ \text{Xx mauve}\end{array}\right. \end{array}\right. \\ \text{CCRRBbXx light blue} & & \end{array}$$

Mauve crossed with dark blue.— Crosses 212 and 213 were made between mauve and dark blue, and in F_1 gave only dark blues. They split up in F_2 into dark blues and mauves. The numbers were very small, and, had more plants been produced, it is possible that other types might have made their appearance; but it is unlikely that any other types would have appeared in the F_1 if both parents were homozygous for all genes, because the blue would have dominated over the red, and the intensifier borne in the dark blue would have been present to give a deeper hue than was found in the mauve. The F_1 plants would be simplex for B, allowing members of the red series to appear in F_2, but no tinged whites nor whites could make their appearance because both C and R would remain duplex. The cross may be represented as follows:

$$\begin{array}{ccc} & F_1 & F_2 \\ \begin{array}{c}\text{CCRRbbXX mauve}\\ \times \\ \text{CCRRBBXX dark blue}\end{array} & \begin{array}{c}\text{CCRRBbXX dark}\\ \text{blue}\end{array} & \text{CCRR}\left\{\begin{array}{l}\text{BBXX dark blue}\\ \text{BbXX dark blue}\\ \text{bbXX mauve}\end{array}\right. \end{array}$$

Mauve crossed with dark purple.— Cross 107 gave 3 dark purples in F_1, which gave dark purples, dark blues (a type often intergrading with the lighter purples), and magentas in F_2. In cross 153 the F_1 plant was recorded and checked as "light blue," but it did not behave as a light blue should. It acted, when selfed, as a light purple might, and threw dark purples, dark blues, and magentas. It must, then, have borne the intensifying genes X and I at least in simplex condition, as in the following schema:

$$\begin{array}{lr} & F_1 \\ \text{CCRRbbXxii mauve} & \\ \qquad\times & \text{CCRRBb}\left\{\begin{array}{l}\text{XXIi dark purple}\\ \\ \text{XxIi light purple}\end{array}\right. \\ \text{CCRRBBXXII dark purple} & \end{array}$$

Type 5 *Magenta* (Plate I)

Magenta crossed with light blue.— Four crosses are recorded in this class and they all gave light purples in F_1. Such crosses should give rise to plants heterozygous for the genes B, X, and I, a condition which would cause the flowers to be light purple. A fifth cross, 197, produced two plants, both of which were recorded as "dark purple."

The fact that these light purple plants threw tinged whites and whites in F_2 indicates that the light blue parent was simplex for R also, and, in the case of cross 197, for X as well, as has since been further indicated by other progenies from it grown by J. J. Pollock and the writer.

Magenta crossed with dark blue.— Three crosses in this class, 188, 190, and 192, gave dark purple and light purple F_1 plants. Two other crosses, 189 and 191, remain to be explained as apparently exceptional cases.

If magenta is crossed with dark blue the F_1 plants will be simplex for I, which, reacting with B from the blue parent, will result in purple, as in the above cases.

Cross 189 gave 3 plants recorded as "magentas," besides 2 dark purples, in F_1. Further data, however, give indication that these "magentas" were really light purples which had been recorded after their colors had begun to break down prior to the flowers' withering.

Cross 191 gave 1 dark purple and 1 light purple. White appeared in F_2, indicating that the F_1 plant from which it came was simplex for R. Since dark blue and magenta are both duplex for R, according to hypothesis, an explanation must be sought for the appearance of the white in F_2. The original blue parent was recorded in the greenhouse as light blue, then checked once as dark blue. The behavior of the cross would indicate that it was really a light blue, which, by hypothesis, can be simplex for R.

Magenta crossed with dark purple.— Four crosses are recorded in this class. They gave all dark purple F_1 plants, with the exception of cross 174, which gave 4 dark purples and 1 light purple. In this case either of the parents might be supposed to have been simplex for I, thus allowing the light purple to appear in F_1. The others need no further explanation than to point out that such a cross could result in only purples, due to the dominance of the blue over the red.

Type 6 *Light blue* (Plate I)

Light blue crossed with light blue.— In cross 140 the single F_1 plant was dark blue. This can be understood if one or both of the light blue parents bore X in simplex condition. In recombination there might result a duplex condition of the gene that would cause the dark blue type. No other cross is recorded in this class.

Light blue crossed with mauve.— In cross 106 the F_1 plants were all dark blues, and these split in F_2 into dark blues, mauves, and pinks. In this case the mauve parent probably brought in the intensifying gene X, which reacted with the gene B from the light blue parent and gave dark blue in the hybrids. If both X and B were simplex in these F_1 hybrids, the recombinations in F_2 would cause dark blues, light blues, mauves, and pinks.

Light blue crossed with dark blue.— Cross 216 gave 1 dark blue and 2 light blues in F_1. This is to be expected on the hypothesis that the light blue parent is simplex for R. A hybrid, then, having both R and X simplex would not be a dark blue but a light blue, as shown in the following schema:

$$\begin{array}{ccl} & & \qquad \text{F}_1 \\ \text{CCRrBBxx light blue} & & \\ \times & \qquad \text{CC}\left\{\begin{array}{l}\text{RRBBXx dark blue}\\ \\ \text{RrBBXx light blue}\end{array}\right. \\ \text{CCRRBBXX dark blue} & & \end{array}$$

In cross 115 the F_1 consisted of 4 purples, showing the light blue parent to have been duplex for R.

Light blue crossed with dark purple.— The two crosses in this class gave dark purples and light purples in F_1, which split into light purples, dark blues, and 1 white in F_2. In such crosses the intensifying factors X and I would be expected to be simplex in the F_1 plants, resulting in purple, but not of the deep, intense hue of the darker type.

Type 7 *Dark blue* (Plate I)

Dark blue crossed with dark purple.— Six crosses give data for this class. In F_1 there were 12 dark purples and 4 light purples; in F_2 there were

26 dark purples, 1 light purple, and 15 dark blues (some of which may have been light purples). It should be noted that in all cases both parents were duplex for B, because no types of the red series made their appearance in the F_2 progeny.

Since the dark blue type lacks the intensifying gene I, this gene would be expected to be simplex in the F_1 plants, altho still potent enough, with the other genes all intact, to produce the dark blue pigment. If the dark blue parent is simplex for B or for X, the gene I will not be able to produce its full effect and some light purples will result.

FLAKING

(Plates II and III)

DESCRIPTION OF THE CHARACTER

The character designated as *flaking* is manifested on the corolla in the form of stripes running parallel from the throat and the rays of the star to the edge of the corolla. These stripes are usually narrow, but may in some cases vary to such width that they constitute a segment of color. In such cases the segment may in turn exhibit stripes of a still deeper hue. On a white corolla the flakes may be pink, mauve, magenta, light blue, dark blue, or purple. The deeper and the lighter saturations of the same hue may lie side by side in the same segment. On a colored corolla the flaking is of a deeper saturation of the same hue as the background.

The whites referred to in this section have all been extracted from the three original flaked plants and are not the same as the plain whites treated in the other sections of this paper. They are a decided cream white (page 10, shade 3, in the Répertoire de Couleurs[5]). This color forms the ground on which the flaking is displayed in the white flaked flowers, and in the unflaked ones it is found pure (Plate II).

The seat of the flakes is in the cell sap of the epidermis of the inner side of the corolla. This character, as studied in the writer's cultures, is dominant over the unflaked condition.

Miss Marryat (1909:45), working with four-o'clocks (*Mirabilis jalapa*), found that flaking proved to be dominant thruout but could offer no satisfactory explanation for it. Correns (1910:424), working with the same species, reported flaking to be dominant. It is a recessive character in Antirrhinum according to Miss Wheldale (1909a:8).

Flowers characterized by localization in flakes or spots of such color as they may have, are very common among cultivated plants, for example, azaleas, sweet williams, stocks, and carnations (Keeble and Armstrong, 1912:292). According to De Vries (1905:311, 322, 323), they occur also in liverleaf (Hepatica), dame's violet (Hesperis), larkspur, periwinkle (*Vinca minor*), tulips, hyacinths, cyclamen, camellia, cockscomb (*Celosia cristata*), and *Clarkia pulchella*, and even in such garden plants as the meadow cranesbill (*Geranium pratense*). He says (page 323 of reference cited): "It is always the red or blue color which occurs in stripes, the underlying ground being white or yellow, according to the presence or absence of the yellow in the original color mixture." He states further (page 325 of the same reference): "Stripes are by no means limited to flowers. They may affect the whole foliage, or the fruits and the seeds, and even the roots."

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[5] See under *Société Française des Chrysanthémistes et René Oberthür*, in *References cited*, page 38.

In *Primula sinensis*, altho the amount of flaking varies considerably, the races breed well-nigh true to this habit (Keeble and Armstrong, 1912:292).

SOURCE OF MATERIAL

The source of this character, in the writer's cultures, was in three vines from the stock numbered 19, the seed of which was obtained from Dreer's nursery. The seed packet was labeled *Dark Blue*, but of the six plants that came to bloom from the seeds, one was plain white, one was solid magenta, and four were cream white with magenta flakes. Three of the last-mentioned were selfed and also used in crosses, and their progeny is discussed later.

THEORETICAL ANALYSIS OF DATA

The progeny from the three plants mentioned in the preceding paragraph, when selfed, were too few to demonstrate the zygotic constitution of the parents, but indicated that at least two of them were heterozygous in regard to the character of flaking.

Cream white flaked progeny in the second inbred generation from these three plants were used as parents in 20 crosses in which the other parent was solid-colored. The F_1 offspring were dominated by the character of flaking when the flaked parent was (presumably) homozygous for the character. When it was (presumably) heterozygous for the character, part of the offspring were flaked and part lacked the flaking. The F_1 flowers were always colored, and where flaking was manifested it appeared as a pattern of deeper hue on the solid color. It appeared on purple, dark blue, light blue, magenta, and tinged white corollas. There were 57 individuals in the F_1 generation, of which 9 were not flaked. All the remainder showed flaking very strongly except one anomalous individual, which showed inconspicuous white flecks on a solid magenta ground.

Taking the progeny of the two heterozygous parents together, 7 were flaked and 5 were not flaked. There were 9 unflaked plants altogether in the F_1 generation; 5 of these were selfed, and gave a progeny of 133 unflaked plants and 1 that was recorded as flaked.

Further data in which flaked plants were used as parents in crosses have since been obtained and are given in tables 6, 7, and 8; the last-named table was made from data of J. J. Pollock's cultures. It should be noted that in all cases except cross 195 (and no cross into which a flaked plant entered has been omitted) the flaking character appears in the F_1 progeny. Some unflaked plants also appear among these F_1 progeny, but their presence is easily explained in that one of the parents may have been simplex for the gene.

All evidence, then, from the F_1 progenies of crosses into which the gene for flaking entered, points to the fact that this gene is a dominant one, and that whenever present in one of the parents in duplex condition the character will be manifest in all the F_1 plants; if it is simplex in one of the parents, unflaked plants also can appear in the F_1 progeny.

TABLE 6. TYPES RESULTING FROM CROSSES BETWEEN FLAKED WHITES AND SOLID-COLORED PLANTS

Pedigree no.	F_1		F_2			
	Flaked solids	Unflaked solids	Flaked solids	Unflaked solids	Flaked whites	Unflaked whites
126	2	2	......	......	......	......
142	1	......	......	......	......	......
147	3	2	......	......	......	......
148	1	......	......	......	......	......
149	1	......	......	......	......	......
163	2	......	1	......	1	......
164	5	......	3	6	......	2
165	4	......	3	5	1	......
166	4	......	1	8	3	1
167	1	......	......	......	......	......
168	4	1	14	8	1	2
195	......	1	......	4	......	......
196	1	2	5	2	2	......
217	4	......	4	4	7	4
218	2	......	4	5	1	4
219	1	......	......	2	......	......
222	2	2	......	4	1	......
223	2	......	3	3	1	......
225	2	......	......	3	2	......
226	1	......	......	......	......	......
	43	10	38	54	20	13

TABLE 7. TYPES RESULTING FROM ALL OTHER CROSSES IN WHICH A FLAKED PARENT WAS USED

Pedigree no.	Seed parent	Pollen parent	F₁			
			Flaked solids	Flaked whites	Unflaked solids	Unflaked whites
401	Flaked white	Flaked solid	10	......	......	......
402	Flaked white	Flaked white	......	16	......	......
403	Flaked white	Unflaked solid	4	......	......	......
404	Flaked white	Unflaked solid	9	......	......	......
405	Unflaked solid	Flaked white	10	......	......	......
406	Flaked white	Unflaked solid	4	......	......	......
408	Unflaked solid	Flaked white	14	......	......	......
409	Flaked white	Flaked solid	3	......	......	......
416*	Unflaked white	Flaked solid	......	2	1	1
417†	Unflaked white	Flaked solid	3	2	1	1
421	Unflaked white	Unflaked solid	......	......	2	......
423	Unflaked solid	Flaked white	7	......	......	1
424‡	Unflaked white	Flaked solid	4	2	7	3
426‡	Unflaked white	Flaked solid				
440	Unflaked white	Flaked solid	8	2	......	......
			76	24	11	6

* The pollen parent was an F₁ flaked plant out of a flaked solid selfed, and so probably simplex for the flaking gene.

† No. 417 had the same (unflaked white) seed parent as no. 416, but the pollen parent was flaked solid (presumably [?] duplex flaked).

‡ Nos. 424 and 426 had the same parents. The pollen parent was simplex for flaking.

Consideration of all the instances in which a flaked solid plant was selfed (and these comprised 23 of various color types) shows that the progeny comprised four types — 53 unflaked solids, 43 flaked solids, 30 flaked cream whites, and 9 unflaked cream whites.

Eighteen flaked cream whites were selfed, and their progeny comprised three types — 3 flaked solids, 117 flaked cream whites, and 25 unflaked cream whites. There were no unflaked solids.

The evidence from all selfed plants also adds support to the theory that the flaking gene is a dominant gene, even when present in simplex condition. In this connection the behavior of plants 222–6 and 222–10, when selfed, is significant. Both were unflaked F_1 plants, and so presumably nulliplex for the gene. The former threw 64 unflaked plants (and possibly 1 flaked plant),[6] and the latter threw 60 unflaked plants only. Plant 222–7, a sib from the same cross, was a flaked light purple. When selfed, 4 of its progeny were not flaked and 1 was flaked. The flaked one, 222–7–2, was selfed and gave 8 flaked and 3 unflaked. The flaked parent in this case, and also the flaked grandparent, were heterozygous dominants.

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[6] Plant 222–6–11 was three times recorded as dark blue flaked purple, and once as unflaked dark blue.

TABLE 8. PROGENIES FROM MR. POLLOCK'S CROSSES IN WHICH FLAKED PLANTS HAD BEEN USED AS PARENTS

Pedigree no.	Seed parent	Pollen parent	F₁			
			Flaked solids	Flaked whites	Unflaked solids	Unflaked whites
107	Flaked solid	Flaked solid	4	......	....	....
109	Flaked solid	Flaked solid	6	......	....	....
110	Flaked solid	Flaked solid	4	......	....	....
125	Flaked solid	Flaked solid	3	1	2	....
126	Flaked solid	Flaked solid	7	1	5	....
129	Flaked solid	Flaked solid	4	......	1	1
132	Flaked solid	Flaked solid	2	2	1	....
112	Flaked white	Flaked white	......	3	....	....
113	Flaked white	Flaked white	......	8	....	....
116	Flaked white	Flaked white	......	12	....	....
119	Flaked white	Flaked white	......	4	....	....
120	Flaked white	Flaked white	......	10	....	....
146	Flaked white	Flaked white	......	3	....	....
133	Flaked white	Flaked solid	2	2	....	....
134	Flaked white	Flaked solid	1	......	....	....
135	Flaked white	Flaked solid	......	1	....	....
137	Flaked white	Flaked solid	1	1	....	....
138	Flaked white	Flaked solid	2	3	....	....
151	Flaked white	Flaked solid	3	6	1	....
152	Flaked white	Flaked solid	2	1	1	....
140	Flaked solid	Flaked white	2	3	....	....
141	Flaked solid	Flaked white	3	......	3	....
142	Flaked solid	Flaked white	3	2	....	....
143	Flaked solid	Flaked white	......	1	1	....
			49	64	15	1

It may be asserted, then, from the evidence afforded by the above data, that the character of flaking is a dominant mendelian character; that when a plant manifests the character, it may be either homozygous for the gene and transmit it to all its progeny, or heterozygous for the gene and transmit it to only a portion (theoretically three-fourths) of its progeny; that when the character is not manifest, the gene for it is lacking and it is incapable of transmitting the character to its offspring.

GENETICS OF COLOR TYPES INVOLVED IN FLAKING

It remains now to inquire into the nature of the genes that cause this particular character.

The pedigree cultures involving this character show that there are white types with colored flakes as well as solid-colored types that are flaked. Indeed, the original material in these studies was of the flaked white type. When crossed with solid-colored types the resultant F₁ plants are in most cases solid-colored and flaked. In some cases the

F_1 progeny comprise both flaked whites and flaked solids, indicating a heterozygous condition of the determiners in one of the parents. The F_1 flaked solids when selfed can throw all four types — flaked and unflaked solids, and flaked and unflaked whites.

If the explanation of this is based on the enzyme theory, which regards such anthocyanic colors as those here dealt with as being the product of interaction between an oxidase and a chromogen, it is seen that the presence of both the chromogen and the oxidase is necessary in order that any color whatever may be visible in the flower. The oxidase may be symbolized by O and the chromogen by C. The flaking, then, can be explained by supposing the presence of a locally distributed oxidase F, which reacts with the chromogen C in the same way as does O except that the area of its influence is restricted, which results in the so-called flakes. This chromogen is usually present in the colorless tissues of white flowers (Kraemer, 1906, and Wheldale, 1909 b: 53). Moreover, the oxidase itself is composed of at least two substances, the peroxide and the peroxidase (as explained on pages 9 to 11), and unless the peroxide is present along with the chromogen and the peroxidase there will be no production of anthocyanic pigment. But for the sake of simplicity in the present discussion the oxidase is considered as a single "unit-character" where homozygous, and will be symbolized by O.

In tables 9 to 17 are given the data in support of this hypothesis, classified and arranged to show the genetical behavior of the flake character and the segregation of the various types, together with hypothetical formulas explanatory of this behavior. The various types may be symbolized as follows:

C = Chromogen (almost [?] always present)
O = Oxidase that reacts with C to give solid color
F = Oxidase that is locally distributed and acts with C to give colored flakes

Possible formulas for the various phenotypes as used in the following tables are as follows:

$$\begin{array}{lll}\text{Plain white} = & \text{CCooff} & (1\text{ a})\\ & \text{cc}\left\{\begin{array}{l}\text{OOFF}\\ \text{OOFf}\\ \text{OOff}\\ \text{OoFF}\\ \text{OoFf}\\ \text{Ooff}\\ \text{ooFF}\\ \text{ooFf}\\ \text{ooff}\end{array}\right. & \begin{array}{l}(1\text{ b})\\ (1\text{ c})\\ (1\text{ d})\\ (1\text{ e})\\ (1\text{ f})\\ (1\text{ g})\\ (1\text{ h})\\ (1\text{ i})\\ (1\text{ j})\end{array}\\ & \text{Ccooff} & (1\text{ k})\\ & \text{CcOoff} & (1\text{ l})\end{array}$$

Flaked white = CCooFF (2)
CCooFf (3)
CcOOFF (4)
CcooFf (5)

$$\text{Flaked solid} = \text{CC}\left\{\begin{array}{ll}\text{OOFF} & (6)\\ \text{OOFf} & (7)\\ \text{OoFF} & (8)\\ \text{OoFf} & (9)\end{array}\right.$$

Unflaked solid = CCOOff (10)
CCOoff (11)

No. 1 a throws only plain whites.
1 b–1 k throw only plain whites.
1 l throws plain whites and unflaked solids.
2 throws only flaked whites.
3 throws flaked whites and unflaked whites.
4 throws flaked solids, unflaked whites, and flaked whites.
5 throws flaked whites and unflaked whites.
6 throws only flaked solids.
7 throws only flaked and unflaked solids.
8 throws only flaked solids and flaked whites.
9 throws all four types — flaked solids and flaked whites, and unflaked solids and unflaked whites.
10 throws only unflaked solids.
11 throws unflaked solids and unflaked whites.

TABLE 9. THE THREE GROUPS INTO WHICH THE PROGENIES OF FLAKED WHITES FALL

	Group 1		Group 2		Group 3
	Flaked solids	Flaked whites	Flaked whites	Plain whites	Flaked whites only
	1	2	5	2	25
	1	7	8	2	15
	1	3	8	4	6
					9
			10	2	7
			38	14	6
					1
			22	1	3
					2
Observed	3	12	91	25	74
Theoretical	3.75	11.25	87	29	74

TABLE 10. CROSSES BETWEEN FLAKED WHITES AND FLAKED SOLIDS

Pedigree no.	Seed parent	Pollen parent	F_1 genotypes	Types actually obtained *			
				Unflaked solids	Flaked solids	Flaked whites	Unflaked whites
401	191–2–5 Flaked white CCooFf	380–3 Flaked magenta CCOoFf	CC {Oo {FF, Ff, ff}; oo {FF, Ff, ff}}	0 —	3 X	7 X	0 —
409	379–12 Flaked white CCooFF	304–3 Flaked solid CCOOFF	CCOoFF	0 —	3 X	0 —	0 —

* The X's in these tables underneath figures represent expected classes such as would appear in F_1 progenies of plants with the postulated formulas. The dashes show where a class should not be represented according to hypothesis.

TABLE 11. CROSSES BETWEEN FLAKED WHITES AND UNFLAKED SOLIDS

Pedigree no.	Seed parent	Pollen parent	F_1 genotypes	Types actually obtained *			
				Unflaked solids	Flaked solids	Flaked whites	Unflaked whites
403	336–1 Flaked white CCooFF	379–3 Unflaked magenta CCOOff	CCOoFf	0 —	4 X	0 —	0 —
404	191–2–37 Flaked white CCooFF	379–3 Unflaked magenta CCOOff	CCOoFf	0 —	9 X	0 —	0 —
405	379–3 Unflaked magenta CCOOff	343–4 Flaked white CCooFF	CCOoFf	0 —	10 X	0 —	0 —
406	336–2 Flaked white CCooFF	379–3 Unflaked magenta CCOOff	CCOoFf	0 —	4 X	0 —	0 —
408	384–4 Unflaked magenta CCOOff	340–9 Flaked white CCooFF	CCOoFf	0 —	14 X	0 —	0 —
					41		
423	384–3 Unflaked magenta CCOOff	191–2–5 Flaked white CCooFf	CCOo {Ff, ff}	1 X	7 X	0 —	0 —

*See footnote to table 10.

TABLE 12. FLAKED WHITES SELFED

Pedigree no.	Number of plant selfed	F_1 genotypes	Types actually obtained *			
			Selfs	Flaked solids	Flaked whites	Unflaked whites
410	379–12 CCooFF	CCooFF	0 —	0 —	23 X	0 —
411	340–15 CCooFF	CCooFF	0 —	0 —	3 X	0 —
412	340–16 CCooFF	CCooFF	0 —	0 —	2 X	0 —

* See footnote to table 10.

TABLE 13. CROSS BETWEEN FLAKED WHITE AND UNFLAKED WHITE

Pedigree no.	Seed parent	Pollen parent	F_1 genotype	Types actually obtained *			
				Unflaked solids	Flaked solids	Flaked whites	Unflaked whites
402	382-5 Flaked white CCooFF	343-1 Unflaked white CCooff	CCooFf	0 —	0 —	16 X	0 —

* See footnote to table 10.

TABLE 14. CROSS BETWEEN FLAKED SOLID AND UNFLAKED SOLID

Pedigree no.	Seed parent	Pollen parent	F_1 genotype	Types actually obtained *			
				Unflaked solids	Flaked solids	Flaked whites	Unflaked whites
421	379-4 Flaked magenta CCOOFf	191-2-27 Unflaked mauve CCOOff	$CCOO\left\{\begin{matrix}Ff\\ff\end{matrix}\right.$	0 X	2 X	0 —	0 —

* See footnote to table 10.

TABLE 15. CROSSES BETWEEN UNFLAKED SOLIDS AND UNFLAKED SOLIDS

Pedigree no.	Seed parent	Pollen parent	F_1 genotypes	Types actually obtained *			
				Unflaked solids	Flaked solids	Flaked whites	Unflaked whites
418	362-1 Unflaked pink CCOOff	384-4 Unflaked magenta CCOOff	CCOOff	13 X	0 —	0 —	0 —
419	362-1 Unflaked pink CCOOff	385-3 Unflaked magenta CCOOff	CCOOff	5 X	0 —	0 —	0 —
420	379-3 Unflaked magenta CCOOff	191-2-27 Unflaked mauve CCOOff	CCOOff	3 X	0 —	0 —	0 —
422†	191-2-27 Unflaked mauve CCOOff	302-3 Unflaked pink CCOOFf	$CCOO\left\{\begin{matrix}ff\\Ff\end{matrix}\right.$	7 X	2 X	0 —	0 —

* See footnote to table 10.

† The pollen parent in this case is an F_1 pink five times recorded as unflaked. Its pollen parent was flaked, its seed parent was unflaked. One of its F_1 sibs was flaked and the other was unflaked like itself. If it bore the gene for flaking, as its behavior in this cross would indicate as well as its parentage, it is strange that its flowers should show no traces of the character.

TABLE 16. CROSSES BETWEEN WHITES AND WHITES

Pedigree no.	Seed parent	Pollen parent	F_1 genotypes	Types actually obtained *			
				Unflaked solids	Flaked solids	Flaked whites	Unflaked whites
413 (same as 438)	191-2-5 Cream white — at some times with a tick of purple CCooFf	314-2 White (F_1 out of cream white × white) CcOoff	CC Cc { OoFf Ooff ooFf ooff	2 X	0 X	1 X	0 X
415	314-4 Unflaked white CCooff	314-2 Unflaked white CcOoff	CC Cc { Ooff ooff	3 X	0 —	0 —	5 X
438 (same as 413)	191-2-5 CCooFf	314-2 CcOoff	CC Cc { OoFf Ooff ooFf ooff	1 X	0 X	0 X	0 X

* See footnote to table 10.

TABLE 17. CROSSES BETWEEN UNFLAKED WHITES AND FLAKED SOLIDS

Pedigree no.	Seed parent	Pollen parent	F_1 genotypes	Types actually obtained *			
				Unflaked solids	Flaked solids	Flaked whites	Unflaked whites
416	314-4 White CCooff	302-1 Mauve flaked mauve CCOoFf	CC { Oo { Ff ff oo { Ff ff	1 X	0 X	2 X	1 X
417	314-4 White CCooff	379-2 Flaked magenta CCOoFf	CC { Oo { Ff ff oo { Ff ff	1 X	3 X	1 X	1 X
424	314-4 White CCooff	380-3 Flaked magenta CCOoFf	CC { Oo { Ff ff oo { Ff ff	4 X	4 X	1 X	0 X
426	Same as for 424	Same as for 424	Same as for 424	0 X	3 X	2 X	0 X
440	Same as for 424	Same as for 424	Same as for 424	0 X	7 X	2 X	0 X
		Totals for last three crosses...		4	14	5	0

* See footnote to table 10.

SUMMARY

In these experiments morning-glory plants were studied in pedigree cultures, and germinal analyses of them were made by means of crossing and subsequent selfing, supplemented by collateral breeding tests from the parents used in the crosses.

Several characters were studied which in heredity behaved in an alternative and mendelian manner. These were color of the seed coat, feathering of the corolla, color of the corolla, and flaking of the corolla.

The seed coat is either black or yellowish brown (tan). Black is the dominant color. Black, being the dominant color in the maternal somatic tissues, may lend character to the seed coat without giving any indication whatever of the nature of the embryo within it. A black seed coat may contain a homozygous or a heterozygous black embryo, or a homozygous tan embryo. A tan seed coat may contain a heterozygous black embryo, but never a homozygous black embryo. It may contain a homozygous tan embryo.

Feathering of the corolla is a mendelian character dominant over its absence.

The color of the corolla differed in the several types in the series here studied. The types were progressively epistatic one to another from white thru pink, magenta, and blue to dark purple.

Anthocyanic colors are due to the action of enzymes upon colorless chromogens, producing thereby colored pigments.

The color types studied in the morning-glory were in complete accord with the enzyme theory. Each epistatic type is due to the addition of one or more genes probably enzymatic in nature which are not present in the hypostatic type.

Flaking is a dominant character in the morning-glory material here studied. It is explained by a hypothesis supposing the character to be due to an enzyme which is locally distributed in the corolla and which reacts with a colorless chromogen to produce the colored flakes. Where it is present without the gene for producing solid color, flaked whites result; when present together with this gene, flaked solids are produced.

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AGRICULTURAL EXPERIMENT STATION

FACTORS INFLUENCING THE ABSCISSION OF FLOWERS AND PARTIALLY DEVELOPED FRUITS OF THE APPLE (PYRUS MALUS L.)

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FACTORS INFLUENCING THE ABSCISSION OF FLOWERS AND PARTIALLY DEVELOPED FRUITS OF THE APPLE (PYRUS MALUS L.)[1]

ARTHUR J. HEINICKE

Observations have shown that normally less than ten per cent of the apple blossoms which open in spring produce fruit. Many of the flowers are lost a few days after the petals fall, and a large number of the partially developed fruits are thrown off during the next few weeks. A rather conspicuous drop, commonly called the *June drop*, occurs in June and July, when the fruits are from one to three centimeters in diameter.

This June drop may or may not be beneficial to the fruit grower. If more than five to ten per cent of the flowers on a tree producing a heavy bloom set fruit, a large quantity of apples must be removed by hand so that the remaining specimens can attain a desirable size and color. On the other hand, apple trees frequently produce an abundance of flowers but little or no fruit is harvested from them, practically all the apples being lost during the June drop or before.

Diseases, insects, and unfavorable weather are often held accountable for the heavy loss of flowers and partially developed fruits. In unsprayed orchards the flowers and fruits that have fallen from the trees often show injury by scab and codling moth. Heavy losses sometimes result from the effects of winter injury, frost, wind, and hail. But in many cases the drop occurs even in the absence of such destructive agents.

The failure of a large proportion of apple blossoms to set, and the heavy loss of partially developed fruits during the June drop, are frequently associated with poor pollination and lack of fertilization. The fact that a large proportion of the apples that fall generally have fewer seeds to the fruit than those that remain on the tree, indicates that the development of seeds is an important factor in fruit setting. Nevertheless, many flowers set fruit even tho they are poorly pollinated, and many fruits remain on the tree even tho they have relatively few seeds.

Obviously, then, there are other factors, aside from the destructive agents previously mentioned, and in addition to poor pollination and lack of fertilization, which influence the abscission of flowers and partially developed fruits of the apple. To study such factors was the object of a

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[1] Also presented to the Faculty of the Graduate School of Cornell University, September, 1916, as a major thesis in partial fulfillment of the requirements for the degree of doctor of philosophy.

AUTHOR'S ACKNOWLEDGMENT. The writer wishes to acknowledge his indebtedness to Professor W. H. Chandler, who proposed the problem and who gave many helpful suggestions during the course of the investigations.

series of observations and experiments that have been in progress during the past three seasons. The results obtained during this time are presented in this bulletin.

SURVEY OF LITERATURE

In early times the success or failure of the fruit crop was attributed largely to weather conditions. This may be inferred from folklore similar to that recorded by Bull (1878).[2] The conditions mentioned in the following quotation, for example, involve an early spring and rather dry weather:

March dust on an apple leaf,
Brings all kinds of fruit to grief.

In another quotation, emphasis is placed on the time of blooming, which likewise involves weather conditions:

If the apple tree blossoms in March,
For barrels of cider you need not *sarch*,
But if the apple tree blossoms in May,
You can eat apple dumplings every day.

The chances of having cold, windy, cloudy, and rainy weather during blooming time would be greater in March than in May. Besides, the weather conditions immediately after fertilization of the flowers would probably be more favorable for fruit development during a late spring than during an early one.

The following extracts from Langley (1729 a) are interesting since he attempts to explain the observed phenomenon on a physiological basis. Referring to the fact that "there are many excellent Kinds of Fruits which produce great Plenty of Blossoms, and but very little Fruit," Langley writes:

> This Sterility is caused by the too great Abundance of Wood, which, when 'tis cover'd over with its beautiful Blossoms, requires a much greater Quantity of Nourishment than the Roots are at that Time able to communicate, and thereby, for want of proper Nourishment, the Embryo Fruits are starved, and more especially when the Soil and Spring are both dry, their Perspirations [transpirations] being then greatest; and if Easterly Winds happen to blow at that Time, their very drying exhaling Nature, is a further Help to the Destruction of the Fruit.

This author also observed that some peaches in which the blossoms open before the leaves, such as Old Newington, have a tendency to produce smaller crops of fruit than such varieties as Albemarle and Catherine, which produce leaves with their blossoms. He believed that the leaves "strongly attract Nourishment from the Roots to the Blossoms."

Referring to the June drop, Langley (1729 b) writes:

> Now [from May 20 to June 20]................ 'tis always seen that great Quantity of Fruit drops, altho' largely grown. Of this all our late Authors on

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[2] Dates in parenthesis refer to bibliography, pages 112 to 114.

> Gardening take Notice, and therefore advise, that the thinning of Fruits be omitted, until it appears that this great Fall is over.................
> .... 'Tis very easy to conceive, that if very dry Weather exhales away that Moisture which is necessary for those Formations [the internal parts of the fruit, such as the kernels, stones, and the like], the Work will be imperfect, and consequently the Fruits must perish.

Several experiments to prevent the drop were attempted during Langley's time. The most successful method found was "to preserve them [the trees] from the very hot Sun, from ten in the Morning until two or three in the Afternoon" by means of a sail cloth. Langley, having tried this method, recommends it to "the Practice of the Diligent and Curious." He adds, " 'Tis very serviceable to give the Trees a gentle Refreshing of Water, at the Time you begin to screen them from the Sun, which they will freely imbibe, and [which] very much strengthens Nature in her Productions."

At the present time the weather is still in many cases held accountable for the failure of blossoms to set fruit. Osterwalder (1907 a), for example, cites the causes which the peasants of Switzerland hold accountable for the wholesale dropping of fruit. Among others, he mentions the "dew rain" of the early morning, which occurs during blooming time and subsequently; the strong mountain winds which prevail shortly after blooming time; and the presence of "honeydew" on the leaves. This honeydew, now known to be the result of aphid work, was formerly associated with local climatic conditions.

Hedrick (1908) has given renewed emphasis to the importance of weather in fruit setting. He is of the opinion that unfavorable weather during blossoming time is the predominating factor in the loss of fruit crops. Besides mentioning the direct and obvious damage done by frost, hail, wind, and the like, to buds, flowers, and fruits, this author points out that rain, cloudiness, wind, and low temperatures during blossoming time offer unfavorable conditions for pollination and subsequent fertilization.

Waite (1894) observed that many varieties of apples and pears are self-sterile. Fruits resulting from cross-pollination were found to be larger and finer specimens than those resulting from self-pollination. The former contained large, plump seeds, and the latter, small and flattened seeds. It was also noted that the ability of a tree to set fruit, either with its own pollen or with that from another tree, was affected by its state of nutrition and its general environment.

Since Waite's work, the need of cross-pollination to insure a set of fruit has received considerable attention. While most of the writers or workers on this question — among whom may be mentioned Hansen (1894), Beach (1895), Budd (1896), Waugh (1896, 1901), Munson (1899), Fletcher (1900), Goff (1901), Green (1902), Close (1903), Lewis and Vincent (1909), Bellair (1910), and Gardner (1913) — recognize, as does Waite, that there are other factors, aside from self-sterility, which cause the falling of blossoms and immature fruits, all of them seem inclined to attach special importance to the necessity of cross-pollination for many varieties of fruits. It is pointed out that the structure of the flowers in many cases is such as to inhibit self-pollination, whereas many flowers have special modifications that seem to favor cross-pollination. The influence of such factors as weather, and the like, which favor or prevent cross-pollination, are emphasized.

Other workers, the chief among these being Müller-Thurgau (1898, 1908) and Ewert (1906, 1907, 1910), while not ignoring the question of pollination, have directed special attention to the importance of nutrition as a factor in fruit setting.

Müller-Thurgau has done most of his work with the grape. He finds (1898) that certain varieties can develop fruits without having the flowers fertilized. If, however, the blossoms of such varieties are emasculated and cross-pollination is prevented by inclosing the flowers in sacks, fruits do not develop. This author holds that the entrance of the pollen tube into the pistil may exert sufficient stimulus to initiate fruit development, even tho fertilization does not occur. The stimulus is believed to be one of a chemical nature which exerts an influence similar to that exerted by fertilization, tho less far-reaching. This influence is not confined to the single berry that has been pollinated or fertilized, but other berries on the same bunch are affected in such a way that they may develop even without the entrance of a pollen tube.

Girdling the cane eight days before the flowers opened prevented the shedding of berries, while similar canes not treated lost their immature fruit. The berries produced were seedless, hence fertilization had not occurred. Müller-Thurgau believes that the ringing afforded better conditions of nourishment for the flowers, so that the pollen tube could germinate and enter the stigma and style. In a subsequent paper (1908) this author records cases in which he obtained a set of seedless grapes even without the stimulus of pollination.

Müller-Thurgau noticed also that the berries on that part of the vine above the girdle were heavier than those borne below the girdle. The latter usually contained some seeds while the former were often seedless. Berries on vigorous shoots were larger than those on relatively weak growth even tho the weak canes were girdled. On a given cane, the berries with seeds were larger than those without seeds, and, furthermore, the size of the fruit was found to be proportional to the number of seeds contained in it.

Vines growing in the open but protected from cold rains lost their fruit, as did plants exposed to the rain. Müller-Thurgau states that rain during warm weather at blooming time does not necessarily have a detrimental effect on subsequent fruiting. He is of the opinion that the falling of blossoms and immature berries of the grape is due to an inadequate supply of easily respirable food. Pollination may overcome a temporary shortage by affording a stimulating influence; fertilization is even more effective in causing the set on weak vines or during unfavorable conditions for assimilation and translocation of food. The conditions that obtain for the grape are said to hold for the apple and the pear as well.

Ewert (1906, 1907, 1909) has given considerable attention to the development of seedless fruits. He believes that the development of such parthenocarpic fruits is possible if an abundance of food is available — such a supply, for example, as would accumulate if the downward movement of sap were inhibited. Ewert assumes that fruit formation on a tree occurs under competition for organic food. Such food, he thinks, has a greater tendency to flow to those fruits that contain seeds, which in turn are the result of cross-pollination. Consequently, seedless fruits developing on the same tree with fruits containing seeds are handicapped, and if the food supply proves inadequate such fruits will eventually fall off.

Inclosing the flower spurs in sacks is said by Ewert to bring about unfavorable conditions for nutrition. Fruits developed on such inclosed spurs, which must be self-pollinated if pollinated at all and which consequently produce very poor seeds, are therefore handicapped in their development. If the ability of a tree to set fruit without pollination is to be determined, it therefore becomes necessary to prevent pollination on all flowers and not merely on a few. When this precaution was observed Ewert obtained seedless fruits which were as large as normal specimens. He found, however, that the same variety was less likely to set parthenocarpically when some of the flowers on the tree were exposed to cross-pollination.

Ewert found also that the dicogamy of the flowers is not always associated with self-sterility, nor is the absence of this condition, which would favor self-pollination, strictly associated with self-fertility. He believes that the question of the need for cross-pollination in fruit setting has been overemphasized. He is of the opinion that cold, rainy weather at blooming time is unfavorable to the setting of fruit, not so much because it hinders fertilization as because such conditions are generally harmful to the development of the young fruit.

Osterwalder (1907 a, 1909) has also given the question of premature drop considerable attention. His studies of the seeds of fruits that remain on the tree, and of those that are shed several weeks after blooming time, have shown that fertilized as well as unfertilized fruits drop. Osterwalder studied also the transpiration by the petals of the flowers. The amount of water lost in this way was found to be much less than that given off by a similar area of leaf surface. He believes that wilting of the floral parts is more likely to result from the loss of water thru the leaves than thru the petals. He holds that fruitfulness depends on nutrient conditions, on the number of fertilized fruits, and on the tendency of the variety to develop fruits parthenocarpically.

Insects and diseases, chiefly codling moth and scab, are often mentioned in literature as causing heavy drops of blossoms and immature fruit (Bailey 1895, Reddick 1912, Wallace 1913). Too rapid vegetative growth, especially of young trees, is sometimes cited as unfavorable to fruit setting (Waite, 1894). A number of other general causes, such as poor soil, plowing during blooming time (Gould, 1915), drought, and the like, are occasionally held accountable for crop failure after blossoms have been produced.

MATERIAL USED IN THESE EXPERIMENTS

The observations and experiments recorded in these pages were made during the course of three summers, 1914 to 1916 inclusive. For the most part the work was done at the experiment station orchard at Ithaca, New York, but observations on a few outlying orchards in western New York were also made. Unless otherwise mentioned, the trees under observation were between forty and fifty years old. About seven years ago these trees were pruned severely, and since that time they have received ordinary care — that is, cultivation, pruning, and thoro spraying.

In this paper the natural drop only is considered, not the drop caused by such external agents as frost, insects, and diseases. In a well-sprayed orchard the drop resulting from scab and from codling moth is practically negligible. Examination of several hundred flowers and small fruits collected from sheets suspended under the trees in the station orchard at Ithaca in the spring of 1916, showed that only about one per cent were affected by scab. In western New York, however, the unfavorable weather did not permit the growers to spray effectively that spring, and, as a result, scab infection on the stems of flowers and young fruits caused a heavy drop. Cases of a similar nature have been reported previously (Bailey 1895, Reddick 1912, Wallace 1913).

MAGNITUDE OF THE FIRST AND OF THE JUNE DROP

Before any experimental work was undertaken, a detailed survey was made of the extent and distribution of the first drop and of the June drop. By *first drop* is meant the loss of flowers and of very slightly developed fruits that occurs within from one to three or four weeks after the petals fall. In the majority of these drops, the ovary and surrounding tissue has not developed beyond the flower stage. In a relatively few cases, the young fruits have attained a diameter of from one-half to one centimeter before they fall.

Flowers developing into fruits after the first drop

The extent of the first drop is indicated by the data given in table 1. The figures are based on a consideration of all flower-bearing spurs found

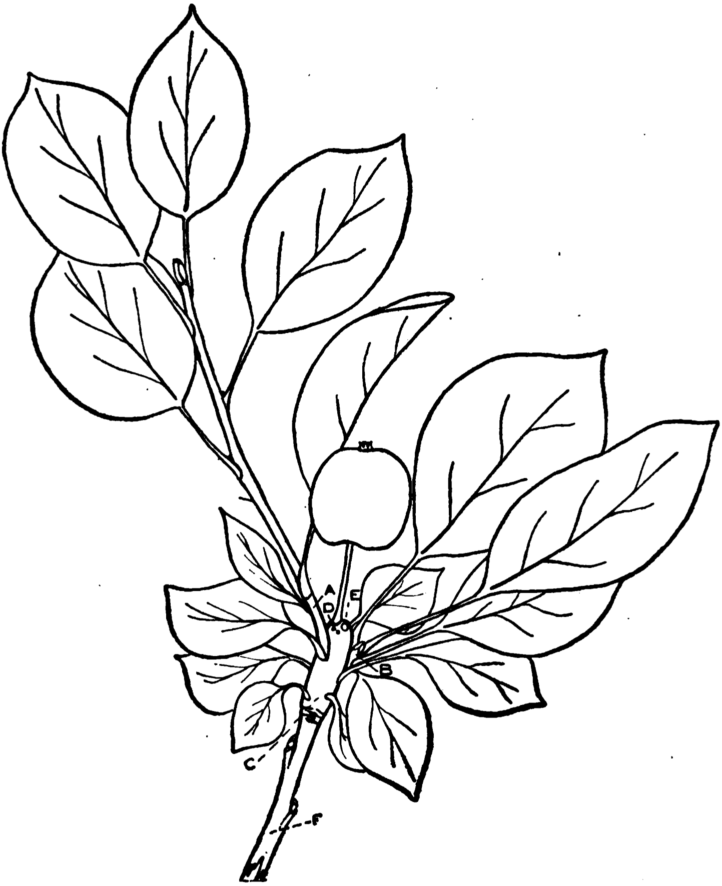

FIG. 1. VIGOROUS SPUR, PRODUCING FRUIT AND LATERAL GROWTH

Lateral shoots are shown at A and B. The spur growth made since spring is shown at C. The leaves on this growth are the bud leaves. The large scar at E is from the stem of an apple that fell at the June drop; the small scars at D are flower-stem scars. A part of the preceding year's growth is shown at F. (⅔ natural size) on a number of different branches from one or more trees of each variety. Normal branches from five to ten years old were chosen. They varied in length between one meter and one and a half meters. The total number of flowers was determined by counting the number of flower-stem scars on the ends of the spurs and the number of fruits remaining on the spurs (fig. 1).

TABLE 1. PERCENTAGE OF FLOWERS DEVELOPING INTO FRUITS AFTER THE FIRST DROP

Variety	Total number of flowers	Number set	Percentage set	Percentage lost
Maiden Blush	271	166	61.2	38.8
Westfield	478	270	56.5	43.5
Fallawater	268	47	17.5	82.5
Baldwin	656	110	16.8	83.2
Tompkins King	1,563	335	21.4	78.6
Rhode Island	840	183	21.8	78.2

From two-fifths to four-fifths of the flowers are lost during the early drop. The varieties given in the table fall into two groups, depending on the number of flowers lost. One group, represented by Maiden Blush and Westfield, lost only half as many as did the other group. All varieties were growing in the same orchard and they bloomed during the same time; consequently they had equal chances of being cross-pollinated. Can the variations noted be due to a tendency toward self-fertility in the first group? Subsequent data may throw some light on this question.

Spurs setting fruit after the first drop

From a practical standpoint, it is interesting to note the percentage of flower-bearing spurs that set fruit. Such data are presented in table 2:

TABLE 2. PERCENTAGE OF FLOWER-BEARING SPURS RETAINING FRUIT AFTER THE FIRST DROP

Variety	Number of spurs with flowers	Number with fruit	Percentage with fruit	Percentage without fruit
Maiden Blush	157	154	98.1	1.9
Westfield	89	84	94.4	5.6
Fallawater	116	79	68.1	31.9
Baldwin	302	183	60.6	39.4
Tompkins King	478	307	64.2	35.8
Rhode Island	534	296	55.4	44.6

The figures are based on counts of all flower-bearing spurs found on a number of different branches taken from one or more trees of each variety. The branches used were similar to those already described.

It is seen from the table that in some varieties practically all spurs set fruit, while in others almost half of the flower-bearing spurs fail to set fruit.

Variations in percentage of spurs setting fruit after the first drop.—The variations found in different branches, in the percentage of spurs that set fruit after the first drop, are shown in table 3. Most of the branches were about one and one-half to two centimeters in diameter at the base, and the wood was from one to at least five years old. Only healthy and apparently normal branches were considered.

TABLE 3. VARIATIONS IN THE PERCENTAGE OF FLOWER-BEARING SPURS THAT SET FRUIT AFTER THE FIRST DROP

Variety and tree	Branch	Total number of spurs	Number setting fruit	Percentage setting fruit
Fallawater, B 2	1	26	19	73.1
	2	36	22	61.1
	3	27	18	66.7
	4	27	20	74.1
Baldwin, B 8	1	24	21	87.5
Baldwin, E 7	1	16	10	62.5
	2	16	9	56.2
	3	20	12	60.0
	4	13	9	69.2
	5	19	8	42.1
	6	12	6	50.0
	7	17	12	70.6
Baldwin, E 10	1	6	4	66.7
	2	9	6	66.7
	3	14	9	64.3
	4	24	17	70.8
	5	23	15	65.2
	6	20	13	65.0
	7	16	11	68.8
	8	25	13	52.0
	9	18	14	77.8
	10	18	9	50.0
	11	16	6	37.5
Westfield	1	60	57	95.0
	2	29	27	93.1
Maiden Blush, A 8	1	69	69	100.0
	2	29	29	100.0
	3	12	12	100.0
	4	28	28	100.0
	5	19	16	84.2

TABLE 3 (*concluded*)

Variety and tree	Branch	Total number of spurs	Number setting fruit	Percentage setting fruit
Tompkins King, C 2	1	33	24	72.7
	2	19	18	94.7
	3	29	21	72.4
	4	10	9	90.0
	5	14	10	71.4
	6	15	10	66.7
	7	36	26	72.2
	8	76	52	68.4
	9	20	11	55.0
	10	23	10	43.5
	11	20	9	45.0
	12	34	14	41.2
	13	25	11	44.0
Tompkins King, C 3	1	35	31	88.6
	2	28	16	57.1
	3	18	9	50.0
	4	33	16	48.5
	5	10	10	100.0
Rhode Island, B 5	1	21	9	42.8
	2	47	22	46.8
	3	100	38	38.0
	4	51	32	62.7
	5	55	31	56.4
Rhode Island, B 3	1	47	39	83.0
	2	49	35	71.4
	3	80	42	52.5
	4	60	28	46.7
	5	24	20	83.3

The figures for the individual branches of a given tree vary considerably. Casual observations have shown that these differences cannot be explained by the location, angle, or exposure of the branch on the tree, since the differences are sometimes found in similarly located branches. For example, in Rhode Island B 5, branches 1, 2, and 3 all came from the top of the tree; in Tompkins King C 2, branches 1 and 5 were from the south side of the tree, branches 2, 3, and 4 were from the north side, branches 6, 7, and 8 arose from the same parent limb on the southwest side of the tree, branches 9 and 10 were growing upward at an angle of 45°, and branches 11, 12, and 13 were drooping. Figures presented later (page 58) afford a probable explanation for the differences noted.

Flowers developing into fruits after the June drop

Totals of flowers on many limbs.— Branches were examined in the latter part of July and in early August for the number of fruits set after the June drop. Data based on all flower-bearing spurs found on various branches are given in table 4. The number of flowers originally borne on each spur was obtained by counting the flower scars and the fruits on the spur. Approximately three to seven per cent of the total number of flowers finally developed into fruits.

TABLE 4. PERCENTAGE OF FLOWERS DEVELOPING INTO FRUITS AFTER THE JUNE DROP

Variety	Total number of flowers	Number set	Percentage set	Percentage lost
Tompkins King	2,849	84	2.9	97.1
Baldwin	770	53	6.9	93.1

Flowers falling at the first drop and at the June drop on fruit-bearing spurs.— The figures in table 5 show the relation between the first drop and the June drop. The data are based on a consideration of all fruit-setting spurs found on several branches from trees of each variety. They do not take into consideration the spurs that bore flowers but failed to set fruit. The first column of figures contains the total number of spurs, and the second contains the total number of flowers found on these spurs. Unless otherwise mentioned, the percentages are based on the original number of flowers.

TABLE 5. FIRST DROP AND JUNE DROP ON FRUIT-SETTING SPURS

Variety	Number of spurs	Number of flowers	Fruits falling at first drop		Fruits falling at June drop			Fruits finally setting	
			Number in drop	Percentage of drop	Number in drop	Percentage of drop		Number set	Percentage set
						(A)	(B)		
Westfield	47	281	7	2.5	227	80.8	82.8	47	16.7
Maiden Blush	54	281	90	32.0	126	44.8	66.0	65	23.1
Tompkins King	03	557	416	74.7	38	6.8	26.9	103	18.5
Fallawater	50	252	192	76.2	10	4.0	16.7	50	19.8
Rhode Island	30	154	116	75.3	8	5.2	21.1	30	19.5
Baldwin	46	258	203	78.7	9	3.5	16.4	46	17.8

(A) Percentage based on original number of flowers.
(B) Percentage based on number of fruits remaining after first drop, obtained by subtracting figures in fourth column from those in third column.

The figures indicate that the June drop is relatively small when the first drop is large. On the other hand, if a large proportion of the flowers begin to form fruits, the June drop will be heavy. Approximately twenty per cent of the flowers on fruit-setting spurs finally develop, which means one fruit to the spur. The variety Maiden Blush has a tendency to develop more than one fruit to the spur. The percentage is somewhat lower than twenty in Westfield, because this variety averages higher than five flowers to the spur. The percentage of flowers which finally set, as given in table 5, is obviously too high if all flower-bearing spurs are considered.

Spurs setting fruit after the June drop

Consideration of spurs from many limbs.— The percentage of flower-bearing spurs that retain fruits after the June drop is given in table 6. These data were obtained during the latter part of July and the early part of August. The figures are based on a consideration of all spurs found on many branches of each variety.

TABLE 6. PERCENTAGE OF FLOWER-BEARING SPURS RETAINING FRUIT AFTER THE JUNE DROP

Variety	Number of spurs with flowers	Number with fruit	Percentage with fruit	Percentage without fruit
Baldwin	1,945	630	32.4	67.6
Tompkins King	368	68	18.5	81.5
Rhode Island	428	73	17.1	82.9

Only about one-sixth to one-third of the flower-bearing spurs become fruit-setting spurs, as indicated by these data.

Variations in percentage of spurs setting fruit after the June drop.— The percentages of fruit-bearing spurs on individual twigs of a number of varieties are given in table 7. Notes concerning the source of the individual twigs were obtained in some cases. These indicate that the angles

TABLE 7. VARIATIONS IN THE PERCENTAGE OF FLOWER-BEARING SPURS THAT SET FRUIT AFTER THE JUNE DROP (1915)

Variety and tree	Branch	Total number of spurs	Number setting fruit	Percentage setting fruit
Baldwin, B 8	1	15	7	46.7
	2	28	9	32.1
	3	11	6	54.5
	4	10	6	60.0
	5	30	5	16.7
	6	188	41	21.8
Baldwin, E 7	1	18	10	55.5
	2	19	11	57.9
	3	8	6	75.0
	4	23	12	52.2
	5	10	7	70.0

TABLE 7 (*concluded*)

Variety and tree	Branch	Total number of spurs	Number setting fruit	Percentage setting fruit
Baldwin, E 7 (*continued*)............	6	215	82	38.1
	7	345	55	15.9
	8	145	30	20.7
	9	281	69	24.5
	10	385	175	45.4
Baldwin, E 10....................	1	25	14	56.0
	2	6	4	66.7
	3	9	6	66.7
	4	14	6	42.9
	5	24	13	54.2
	6	23	7	30.4
	7	20	9	45.0
	8	16	9	56.3
	9	25	8	32.0
	10	18	10	55.5
	11	18	9	50.0
	12	16	4	25.0
Tompkins King, C 1...............	1	146	21	14.4
Tompkins King, C 2...............	1	42	7	16.7
	2	31	2	6.5
	3	25	3	12.0
Tompkins King, C 3...............	1	35	10	28.6
	2	28	9	32.1
	3	18	4	22.2
	4	33	9	27.3
	5	10	3	30.0
Rhode Island, B 5.................	1	27	1	3.7
	2	23	1	4.3
	3	18	2	11.1
	4	17	1	5.9
	5	35	1	2.9
Rhode Island, B 3.................	1	88	30	34.1
	2	127	21	16.5
	3	6	1	16.7
	4	34	5	14.7
	5	53	10	18.9

at which the branches grow and their location on different parts of the tree cannot be held accountable, in themselves, for the variations found. For example, in Baldwin B 8, branches 1 and 3 were growing in an upright position, and branches 2 and 4, found on the same side of the tree, were drooping; in Baldwin E 7, branches 1 to 4 were obtained from the top of the tree, and branches 5 to 10 from limbs close to the ground.

RELATION BETWEEN AMOUNT OF BLOOM AND SET OF FRUIT

In the spring of 1916 most of the mature trees in the station orchard at Ithaca produced a heavy bloom. Individual limbs on many of the trees, however, bore relatively few flowers. A number of such limbs, with a light bloom, were labeled. Corresponding limbs with a heavy bloom, but otherwise like the former — having a similar exposure, and arising from the same parent limb — were also labeled. After the June drop, the total number of flower-bearing spurs on each limb was obtained, together with the number of spurs that had set fruit. The data from some of the branches are recorded in table 8:

TABLE 8. PERCENTAGE OF SPURS SETTING FRUIT ON LIMBS WITH HEAVY BLOOM AND ON THOSE WITH LIGHT BLOOM

Variety	Limbs with light bloom			Limbs with heavy bloom		
	Number of spurs	Number set	Percentage set	Number of spurs	Number set	Percentage set
Baldwin, tree 1	52	40	76.9	116	18	15.5
Baldwin, tree 2	47	38	80.8	76	39	51.3
Fallawater	21	10	47.6	255	21	8.2
Westfield	25	19	76.0	250	20	8.0
Total	145	107	73.8	697	98	14.1

A larger percentage of spurs set fruit in the limbs with the relatively light bloom. This fact is easily apparent on inspection, even without accurate counts. Hence, only a relatively few limbs were removed from the trees to obtain records, the remainder being used for other purposes. An explanation for the results obtained is afforded by subsequent observations.

SET OF FRUIT ON LIMBS WITH LARGE LEAVES AND ON LIMBS WITH SMALL LEAVES

It is not uncommon to find individual limbs with leaves noticeably smaller than those on the remaining limbs of the same tree. In the spring of 1916, such small-leaved limbs which had produced a heavy bloom were labeled. Limbs with normal leaves, but otherwise similar, were likewise labeled. The percentage of flower-bearing spurs that set fruit was determined for each group of branches. Data of several of the many limbs labeled are contained in table 9:

TABLE 9. PERCENTAGE OF SPURS SETTING FRUIT ON WEAK AND ON VIGOROUS LIMBS

Variety	Vigorous limbs with large leaves			Weak limbs with small leaves		
	Number of spurs	Number set	Percentage set	Number of spurs	Number set	Percentage set
Unknown	164	94	57.3	219	33	15.1
Tompkins King	223	67	30.0	207	34	16.4
Total	387	161	41.6	426	67	15.7

The percentage of flower-bearing spurs that set fruit was greater on the branches with large leaves than on those with small leaves. The same condition prevailed on the other limbs that had been labeled, as was determined by careful inspection. These results can probably be explained on the basis of data presented later in these pages.

SET OF FRUIT AS INFLUENCED BY THE LOCATION OF THE SPUR ON THE TWIG GROWTH OF DIFFERENT YEARS

Observations were made to determine whether flower-bearing spurs arising from wood of different ages would be more likely to set fruit in some cases than in others. Data regarding this point are given in tables 10, 11, 12, and 13. These figures were obtained during the summer of 1915, hence the spurs on 1914 twig growth came from lateral buds. Ordinarily, few lateral buds form blossoms in New York State, and such formation may be ascribed to the unusually favorable conditions for fruit-bud formation which prevailed during 1914 — a wet spring followed

TABLE 10. PERCENTAGE OF FLOWERS DEVELOPING INTO FRUITS AFTER THE FIRST DROP, ON SPURS ARISING FROM WOOD OF DIFFERENT AGES

Year's wood	Tompkins King, tree 1			Tompkins King, tree 2		
	Number of flowers	Number set	Percentage set	Number of flowers	Number set	Percentage set
1914	65	11	16.9	25	3	12.0
1913	379	97	25.6	101	34	33.7
1912	129	44	34.1	85	12	14.1

by a dry, sunny season. Comparatively few of the flowers arising from such buds set fruit, as may be seen from the figures. Other observations indicate that the length of the 1914 wood influenced the setting ability of the flowers arising from the lateral buds. In a number of cases in which the growth was twenty-five centimeters and the terminal bud produced a flower, few, if any, lateral buds set. When the growth was less vigorous, it was not uncommon to find fruits produced on the lateral buds.

TABLE 11. SET ON SPURS ARISING FROM WOOD OF DIFFERENT AGES

Year's wood	Tompkins King, tree 1			Tompkins King, tree 2			Baldwin			Rhode Island		
	Number of spurs	Number set	Percentage set	Number of spurs	Number set	Percentage set	Number of spurs	Number set	Percentage set	Number of spurs	Number set	Percentage set
1914..	5	3	60.0	15	7	46.7	12	5	41.7	16	4	25.0
1913..	36	25	69.4	79	54	68.4	86	63	73.3	10	5	50.0
1912..	16	7	43.8	25	20	80.0	34	24	70.6	....	....	....
1911..	11	4	36.4	....	....	......	32	14	43.8	....	....	....
1910..	31	16	51.6	....	....	......	14	5	35.7	....	....	....

TABLE 12. PERCENTAGE OF FLOWERS DEVELOPING INTO FRUITS AFTER THE JUNE DROP, ON SPURS ARISING FROM WOOD OF DIFFERENT AGES

Year's wood	Tompkins King, tree 1			Tompkins King, tree 2		
	Number of flowers	Number set	Percentage set	Number of flowers	Number set	Percentage set
1914	65	3	4.6	25	3	12.0
1913	379	46	12.1	191	34	17.8
1912	129	29	22.5	85	12	14.1
1911	......	......	......	65	4	6.2
1910	......	......	......	169	27	16.0
1909	......	......	......	96	12	12.5

Such observations can be interpreted on the basis of nutrition, that is, an adequate supply of stored food which is readily available in spring, as well as a sufficient supply of water. So long as active growth continues, the assimilate is probably translocated to the growing parts; little is left for storage and fruit-bud formation in the lateral buds. After growth finally ceases on long twigs, the time remaining for active assimilation is inadequate for abundant storage. On the other hand, short twigs stop elongating much sooner; consequently, the lateral buds on short twigs can store the food which is utilized for continued length growth

TABLE 13. SET ON SPURS ARISING FROM WOOD OF DIFFERENT AGES

Year's wood	Tompkins King, tree 1			Tompkins King, tree 2			Tompkins King, tree 3			Baldwin, tree 1			Baldwin, tree 2		
	Number of spurs	Number set	Percentage set	Number of spurs	Number set	Percentage set	Number of spurs	Number set	Percentage set	Number of spurs	Number set	Percentage set	Number of spurs	Number set	Percentage set
1914	15	3	20.0	5	1	20.0	11	3	27.3	20	8	40.0	12	3	25.0
1913	79	39	49.4	36	7	19.4	49	23	46.9	89	47	52.8	273	84	30.8
1912	25	17	68.0	16	4	25.0	16	7	43.8	36	17	47.2	......	......	....
1911	......	......	......	......	......	......	13	5	38.5	34	10	29.4	......	......	....

on long twigs. No analyses are available to show that such a condition actually exists.

In several cases, the spurs arising from 1913 twig growth set more fruit than did spurs arising from older wood. In other cases, however, spurs on older twigs were more fruitful than those on younger growth. This fact suggests that the ability of a bud to develop into a fruit-setting spur is determined to some extent during the year when it is formed in the axil of a leaf. It should be mentioned, in this connection, that many limbs have no flower-bearing spurs on a given year's growth, whereas such spurs are borne on younger and on older wood of the same limb. Then, too, the proportion of buds that develop into fruiting spurs varies with the different year's growth on the same branch.

Apparently the age of the spur alone, at least from the second to the fourth or the fifth year, has little influence on its fruitfulness. Spurs arising from wood several meters from the periphery of the tree would generally be in a less desirable position so far as exposure to light and free circulation of air are concerned. This condition would probably have an unfavorable influence on the nutrition of the fruit bud.

SET OF FRUIT ON SPURS FORMED ON DIFFERENT PARTS OF A GIVEN YEAR'S GROWTH

The vigor of the individual buds found on the twig growth of a given year varies considerably. This can be determined by observing the fate of the buds the year after they have been formed. In most of the varieties, buds near the beginning, and in many cases those just before the end, of a year's growth remain dormant (Koopmann, 1896). If a year's growth happens to be from thirty to forty centimeters, a third zone of weak buds may be found near the center of that particular year's growth. The transition from dormant buds to those that produce strong spurs, or even short twigs, is usually, but not always, a gradual one. The strongest spurs are generally found just before the terminal zone of dormant buds, and before the middle zone if there is one. The leaves in the zones bearing weak buds will usually be the first to turn yellow and fall off if the twigs are removed from the tree and placed in beakers containing water. Such leaves likewise are the first to be shed in the autumn.

Just what causes these variations in bud vigor is not definitely known. They are found even in upright twigs growing at the top of the tree, where light conditions for the different buds are approximately the same. The nutrient supply available at the time of formation of the individual bud may determine its vigor. It is probable that the water supply from the soil, the temperature, the humidity, cloudiness, and other environmental conditions, have marked influence on the nutrition.

In the summer of 1914, the fruit borne on spurs arising from 1912 or 1913 wood was found near the end of the season's growth in most cases. The percentage of flower-bearing spurs that set fruit in the terminal parts of a given year's growth, as compared to the set on the spurs in the lower halves of the same twigs, is shown in table 14. It is seen that there are fewer flower-bearing spurs in the basal half of the year's growth, and a smaller percentage of these basal spurs set fruit. The results would probably have been more striking if only the relatively short twigs had been considered. The long twigs, as has been mentioned, usually show a middle zone of weak or dormant buds, which are generally preceded by fruit-setting spurs. In such twigs, fruit-setting spurs would be found in the basal half of the year's growth.

TABLE 14. SET OF FRUIT ON SPURS FORMED ON DIFFERENT PARTS OF A GIVEN YEAR'S GROWTH

Variety	Spurs in upper half of year's growth			Spurs in lower half of year's growth		
	Number of spurs	Percentage set after first drop	Percentage set after June drop	Number of spurs	Percentage set after first drop	Percentage set after June drop
Baldwin.......	136	64.3	50.0	90	53.2	40.0
Tompkins King.	47	63.8	34.0	24	45.8	12.5

RELATION BETWEEN NUMBER OF FLOWERS TO THE SPUR, AND ABILITY OF THE SPUR TO SET FRUIT

The number of flowers on an apple spur varies from two to seven. Casual observations seemed to indicate that there is a relation between the number of flowers produced by the spur and its ability to bear fruit. Consequently, a more careful study of this question was undertaken.

Average number of flowers on spurs holding fruit for varying lengths of time

Records were made of the number of flowers borne on spurs that lost all fruit at the first drop, on those that held fruit until the June drop but not longer, and on those that finally set fruit. The data are recorded in table 15:

TABLE 15. AVERAGE NUMBER OF FLOWERS ON SPURS HOLDING FRUIT FOR VARYING LENGTHS OF TIME

Variety	Spurs losing all fruit at first drop			Spurs holding fruit until the June drop			Spurs finally setting fruit		
	Number of spurs	Number of flowers	Average number of flowers to the spur	Number of spurs	Number of flowers	Average number of flowers to the spur	Number of spurs	Number of flowers	Average number of flowers to the spur
Tompkins King..	39	144	3.69	23	114	4.96	64	354	5.53
Tompkins King...	52	257	4.94	37	216	5.84	35	204	5.83
Rhode Island....	60	271	4.52	116	569	4.91	....	......	....
Westfield........	....	......	....	47	221	4.70	35	211	6.03
All varieties..	151	672	4.45	223	1,120	5.02	134	769	5.74

There seems to be a correlation between the number of flowers on a spur and the ability of the spur to hold fruit. Spurs that lose all flowers and fruits during the first drop have the smallest average number of flowers, and those that finally set have the largest average number of flowers.

Set of fruit on spurs with varying numbers of flowers

The spurs from several branches were grouped in lots based on the number of flowers borne. The percentage of spurs bearing fruit in each case is recorded in table 16:

TABLE 16. SET OF FRUIT ON SPURS WITH VARYING NUMBERS OF FLOWERS

Variety	Branch	Spurs with 4 flowers		Spurs with 5 flowers		Spurs with 6 flowers	
		Number of spurs	Percentage set	Number of spurs	Percentage set	Number of spurs	Percentage set
Baldwin..........	1	7	42.9	32	56.2	63	*65.1
	2	7	42.9	39	41.0	70	†48.1
Tompkins King....	1	18	11.1	33	51.5	62	*70.9
	2	18	11.1	33	21.2	62	†33.9
Rhode Island......	......	30	50.0	103	70.9	26	*79.2

* After the first drop.
† After the June drop.

These data likewise show that the fruit-bearing ability of a spur is closely related to the number of flowers produced by the spur. The spurs having the greatest numbers of flowers show the highest percentage set.

Percentage of flowers developing into fruits on spurs producing varying numbers of flowers

In many cases the spurs bear more than one fruit. Do individual flowers on spurs producing six blossoms have to compete more for their portion of food and water, than flowers on spurs producing a smaller number of blossoms? The data in table 17 contain an answer to this question. The figures indicate that a higher percentage of flowers develop into fruits on spurs producing six flowers than on spurs producing four or five flowers.

TABLE 17. PERCENTAGE OF FLOWERS DEVELOPING INTO FRUITS ON SPURS WITH VARYING NUMBERS OF FLOWERS

Variety	Branch	Spurs with 4 flowers		Spurs with 5 flowers		Spurs with 6 flowers	
		Number of flowers	Percentage set	Number of flowers	Percentage set	Number of flowers	Percentage set
Westfield	......	28	28.9	150	54.0	228	†57.0
Baldwin	1	28	10.4	195	82.0	420	*90.0
	2	60	56.7	80	60.0	102	*72.5
Maiden Blush	1	24	45.1	110	60.0	138	*71.0
	1	24	20.9	110	20.0	138	†23.2

*After the first drop.
†After the June drop.

RELATION BETWEEN LENGTH OF SPUR GROWTH MADE DURING PRECEDING SEASON, AND FRUITFULNESS OF THE SPUR

In 1915 it was observed that many of the fruits were borne on spurs which had elongated more than two centimeters during the previous season. This fact was first noted in studying the set on Mr. F. W. Cornwall's Baldwin orchard at Pultneyville, New York. All flower-bearing spurs found on large branches from several trees were placed in two groups. The first group contained spurs that had made a growth of two centimeters

TABLE 18. SET OF FRUIT IN 1915 ON SPURS MAKING DIFFERENT GROWTH LENGTHS DURING THE PRECEDING YEAR

Branch	Spurs making 2 centimeters growth or more during 1914			Spurs making less than 2 centimeters growth during 1914		
	Number of spurs	Number set	Percentage set	Number of spurs	Number set	Percentage set
1	17	13	76.5	34	9	26.5
2	24	13	54.2	57	18	31.6
3	37	21	56.8	58	16	27.6
4	36	25	69.4	67	17	25.4
Total	114	72	63.2	216	60	27.8

or more during 1914 — the year preceding that in which fruit was borne; the second group contained spurs that had made less than two centimeters growth in the same period. The percentage of spurs setting fruit in each group is given in table 18.

In 1916 similar data were obtained at the station orchard at Ithaca. All spurs that had elongated one centimeter or more in 1915 were placed in one class, and those that had grown less than one centimeter were placed in another. The percentages of spurs that produced fruit are recorded in table 19. It is seen from the table that spurs which have elongated more than one centimeter during any one year are more likely to set fruit in the following year than are spurs that have made a weaker growth.[3]

TABLE 19. SET OF FRUIT IN 1916 ON SPURS MAKING DIFFERENT GROWTH LENGTHS DURING THE PRECEDING YEAR

Variety	Branch	Spurs making 1 centimeter growth or more during 1915			Spurs making less than 1 centimeter growth during 1915		
		Number of spurs	Number set	Percentage set	Number of spurs	Number set	Percentage set
Strawberry	1	434	138	31.8	721	118	16.4
	2	405	122	30.1	659	113	17.1
	3	237	88	37.1	445	51	11.5
	4	567	182	32.1	878	162	18.4
Total	......	1,643	530	32.3	2,703	444	16.4
Baldwin	1	67	57	85.1	52	25	48.1
	2	75	36	48.0	59	14	23.7
	3	50	31	62.0	117	30	25.6
	4	44	22	50.0	68	14	20.6
	5	84	69	82.1	61	8	13.1
Total	......	320	215	67.2	357	91	25.5
Tompkins King	1	80	40	50.0	63	18	28.6
	2	23	6	26.1	48	8	16.7
Total	......	103	46	44.7	111	26	23.4
Grand total	......	2,066	791	38.3	3,171	561	17.7

Casual observations during 1915 seemed to indicate that flowers produced in the terminal bud of twigs making more than approximately twenty centimeters length growth in 1914 did not set as well as did flowers on shorter twigs. In 1916, however, the same varieties were setting at the ends of long twigs.

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[3] Yeager (1916), in a bulletin which was received here while this paper was being prepared for publication, likewise reports a correlation between the amount of growth that a spur makes in one year and its production in the following year.

RELATION BETWEEN WEIGHT OF THE FLOWER-BEARING SPUR AND ITS FRUITFULNESS

Most writers on topics relating to fruit setting agree that the vigor of the tree is a factor to be considered. It is generally assumed that excessive vegetative growth is opposed to fruit production. No definite figures, however, are available regarding the influence of the vigor of the individual spur on fruit bearing.

When the fruit bud opens in spring, a short spur is produced varying in length from 0.3 to 2 centimeters. This new growth bears leaves laterally and a cluster of flowers terminally. It seems safe to assume that this spur growth is made at the expense of stored food. The stored food is the result of photosynthetic activity during the previous year. The amount of this early spur growth with its leaves and flowers can therefore be taken as an index to vigor.

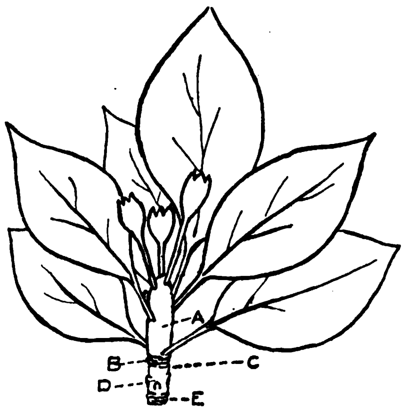

FIG. 2. PREPARATION OF SPUR PREVIOUS TO WEIGHING

The point C just below the ring of bud-scale scars, B, indicates the point at which the present year's growth, A, is cut from the preceding year's growth, D E. The fruits are removed before the spur is weighed. (Slightly reduced)

Weights of setting and of non-setting spurs

The relation of vigor to the fruit-setting ability of the tree was studied by ascertaining the weights of a large number of flower-bearing spurs. The spur growth of the current year was cut from the parent spur just at the base of the ring of bud scales protecting the bud from which the current year's growth came (fig. 2). The spurs were weighed in a turgid condition. The weights were taken early in the season, and any growth arising from a lateral bud on the current season's spur was removed before weighing.

All flower-bearing spurs found on a given limb were considered; the setting and the non-setting spurs were therefore produced on the same parent branch. The data given in table 20 are representative of the weights of setting and of non-setting spurs.

According to the table, the setting spurs on a given branch are heavier than the non-setting spurs on the same branch in all cases. It should be noted that the average weight of spurs may be greater on one branch than on others. More specific observations regarding this point are discussed later (page 73).

TABLE 20. WEIGHTS OF SETTING AND OF NON-SETTING FLOWER-BEARING SPURS

Variety	Branch	Setting spurs			Non-setting spurs		
		Number of spurs	Total weight (grams)	Average weight (grams)	Number of spurs	Total weight (grams)	Average weight (grams)
Baldwin	1	97	174.46	1.80	115	179.56	1.56
	2	66	210.50	3.19	47	91.87	1.95
	3	46	128.64	2.80	24	58.42	2.43
	4	139	383.60	2.76	112	162.40	1.45
	5	46	109.94	2.39	42	55.02	1.31
	6	42	105.00	2.50	16	24.96	1.56
Tompkins King	1	37	107.75	2.91	81	137.93	1.70
	2	34	59.50	1.75	175	134.75	0.77
Fallawater	......	10	8.12	0.81	42	23.24	0.55
Rhode Island	......	30	128.24	4.27	58	180.35	3.11
Westfield	......	48	102.74	2.14	48	91.92	1.92
Total	......	595	1,518.49	2.55	760	1,140.42	1.50

Set of fruit on spurs of different weights

The flower-bearing spurs from a Fallawater branch were classified, according to their weights, as heavy, medium, and light. The average weight of each lot is given in table 21, together with the percentage of spurs that produced fruit:

TABLE 21. SET OF FRUIT ON SPURS OF DIFFERENT WEIGHTS

Number of spurs	Average weight (grams)	Percentage with fruit
18	4.53	61.1
18	2.37	25.5
18	1.21	16.6

The heaviest spurs produced the most fruit, and the lightest produced the least. These data alone are insufficient to establish the relation between set of fruit and vigor of spur, but they lend additional support to the facts presented in tables 20 and 22.

Weights of spurs holding fruits for varying lengths of time

The weights of spurs that lost all fruit at the first drop, of those that held fruit until the June drop, and of those that held fruit after the

June drop, were obtained in the case of a large limb taken from a Baldwin tree in July, 1915. The scars on the spurs that had lost fruits during the June drop were easily distinguishable from the smaller scars of the flowers and fruits that had been lost earlier. The data are recorded in table 22:

TABLE 22. WEIGHTS OF SPURS HOLDING FRUITS FOR VARYING LENGTHS OF TIME

Time spur held fruit	Number of spurs	Total weight (grams)	Average weight (grams)
Until first drop	30	88.12	2.94
Until June drop	28	92.23	3.29
After June drop	30	128.23	4.27

The spurs that finally set fruit are heavier than the others. Those that hold fruit until the June drop weigh more than those that lose all fruit during the first few weeks.

Relation between weight, or vigor, of the fruit-bearing spur, and number of fruits borne by it

In several cases the fruit-bearing spurs from a given limb were divided into two lots. One lot consisted of spurs that produced one fruit, the other of spurs that produced two fruits. The average weight of each lot was obtained. The figures are recorded in table 23, and show that spurs bearing but one fruit are not so heavy as those bearing two fruits:

TABLE 23. RELATION BETWEEN WEIGHT OF THE SPUR AND NUMBER OF FRUITS BORNE BY IT

Variety	Branch	Spurs with one fruit		Spurs with two fruits	
		Number of spurs	Average weight (grams)	Number of spurs	Average weight (grams)
Baldwin	1	25	1.60	25	1.84
Baldwin	2	60	3.08	39	3.62

The relation between the vigor, or weight, of a spur and its tendency to produce more than one fruit is further emphasized by the data in table 24. The spurs included in the strong lot had much larger leaves, and more leaves to the spur, than those in the weak lot. All spurs were taken from the same branch. The table shows that the strong lot contained more spurs with two fruits than did the weak lot.

TABLE 24. SET OF FRUIT ON STRONG AND ON WEAK SPURS

Variety	Strong spurs		Weak spurs	
	Number of spurs	Percentage with two fruits	Number of spurs	Percentage with two fruits
Baldwin	94	34.0	33	15.2

The fact that fruit-setting spurs are heavier on the average than those that do not set fruit, suggests that the presence of the fruit on the spur may in itself be a stimulant to increase the weight of the spur. It is probable that the food which is translocated to the developing fruit accumulates just beneath the fruit stem, and in that way increases the weight of the fruit-bearing spur. Such an accumulation of food, however, is usually not apparent until after the fruits have attained considerable size. The presence of a fruit on a relatively weak spur does not materially increase its weight early in the season, nor does the absence of a fruit from a vigorous spur put it in the weak class. The weight of the spur is closely correlated with other conditions, as may be seen from the following paragraphs.

RELATION BETWEEN WEIGHT OF THE SPUR AND NUMBER OF FLOWERS TO THE SPUR

As previously shown, spurs with many flowers have a greater tendency to set fruit than those with a small number of flowers. The question whether there is a relation between the number of flowers on the spur and its weight, naturally suggests itself. Representative data regarding this question are contained in table 25. The figures are based on a consideration of spurs on a limb from a Maiden Blush tree. It is seen that spurs with many flowers are usually heavier than those with few flowers.

TABLE 25. RELATION BETWEEN WEIGHT OF THE SPUR AND NUMBER OF FLOWERS ON IT

Flowers to the spur	Number of spurs	Total weight (grams)	Average weight (grams)
4	6	10.58	1.76
5	19	51.77	2.72
6	18	60.41	3.36

RELATION BETWEEN WEIGHT OF THE SPUR AND LENGTH OF THE PREVIOUS SEASON'S GROWTH

Data are presented in tables 18 and 19 (pages 65 and 66) indicating that spurs making a relatively short growth during the season previous to the one in which they bear flowers are less likely to set fruit than spurs making a longer growth. Is there any relation between such length growth and the weight of the new spur growth arising from the terminal bud?

In a study of this question the flower-bearing spurs from several Baldwin limbs were divided into two lots. One lot consisted of spurs from buds terminating more than one centimeter of 1915 growth; in the other lot, the spurs were from buds terminating less than one centimeter of 1915 growth. The total weight of each lot and the average weight of the spurs are given in table 26:

TABLE 26. RELATION BETWEEN WEIGHT OF THE SPUR AND LENGTH OF THE PREVIOUS SEASON'S GROWTH

Variety	Branch	Spurs making more than 1 centimeter growth during previous season			Spurs making less than 1 centimeter growth during previous season		
		Number of spurs	Total weight (grams)	Average weight (grams)	Number of spurs	Total weight (grams)	Average weight (grams)
Baldwin...........	1	75	199.6	2.66	59	83.1	1.41
Baldwin...........	2	15	33.5	2.23	53	94.0	1.77
Baldwin...........	3	10	16.8	1.68	27	29.8	1.10
Baldwin...........	4	129	402.0	3.12	122	143.0	1.17
Total.........	....	229	651.9	2.85	261	349.9	1.34

The figures indicate that spurs making a relatively long growth during the preceding year will produce heavier and more vigorous buds in the following year than those making a short growth. That the spurs arising from buds terminating several centimeters of a given season's growth are more vigorous than spurs arising from buds on short spur-growth, may be observed even before the individual flower buds open (fig. 3).

It should not be assumed, however, that vigorous buds are produced only on relatively long growth and that spurs making a short growth are always weak. Cases in which the reverse conditions obtain are occasionally found. Nevertheless, the length of spur growth produced during the previous season forms a very convenient and satisfactory guide to the vigor of a spur, and the best criterion for a probable set is found in this character.

The advantages of having a basis for estimating the probable set are numerous. For example, plant breeders working on the apple might save considerable time and secure a higher percentage of set if they confined their work of cross-pollination to the vigorous, many-flowered spurs that have made several centimeters growth during the preceding season.

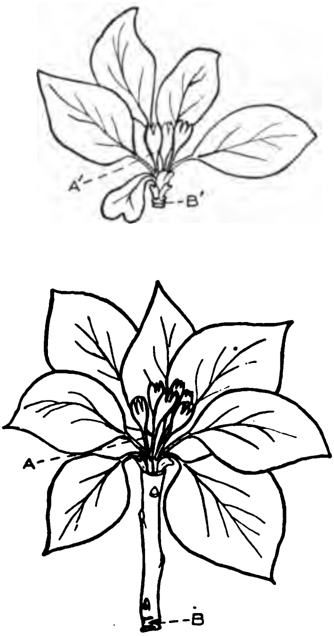

FIG. 3. LEAVES AND FLOWERS ON SPURS OF DIFFERENT VIGOR

Lower figure, a typical vigorous spur of the variety Tompkins King; upper figure, a spur below medium in vigor, of the same variety. The spurs were obtained just before the flower buds opened. The number of flowers (A, A'), the number and size of the leaves, and the length of the preceding year's spur growth (B, B'), may be compared. (½ natural size)

RELATION BETWEEN WEIGHT OF THE NEW SPUR GROWTH AND DIAMETER OF THE CONDUCTING TISSUE

In cutting off the spur growth just previous to weighing, it was observed that the diameter of the cylinder of conducting tissue varied between 1 and 2.5 millimeters (fig. 4). Closer inspection showed that the spurs with conducting tissue of large diameter had a greater leaf surface than spurs with conducting tissue of smaller diameter. The weights of new spur growth, together with the diameters of the conducting tissue of the spurs, are given in table 27. The material used was from a large limb on a Tompkins King tree. All flower-bearing spurs on the limb were considered.

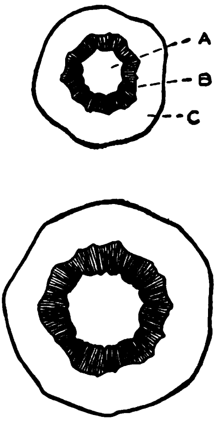

FIG. 4. CONDUCTING CYLINDERS IN SPURS OF DIFFERENT VIGOR

Cross section of a vigorous spur, below, and of a moderately vigorous spur above. A, pith; B, xylem (conducting tissue); C, cortex. The section was obtained just above the ring of scars. Outline from camera lucida drawing. × 6

The weights of the spurs show a relation to the diameters of the cylinders of conducting tissue. The smaller the conducting tissue is in diameter, the lighter is the new spur growth.

It should be noted that spurs with conducting tissue of large diameter are sometimes produced from buds that were terminal to less than one centimeter of spur growth. In all such cases, however, the spurs are large, in accordance with the preceding data. Likewise, when spurs show relatively small conducting-tissue cylinders, they are usually light in weight even tho they arise from buds terminal to several centimeters growth.

TABLE 27. RELATION BETWEEN DIAMETER OF CONDUCTING TISSUE AND WEIGHT OF SPUR

Relative diameter of conducting tissue	Number of spurs	Total weight (grams)	Average weight (grams)
Small (1–1.5 mm.)	74	110.7	1.50
Medium (1.6–2 mm.)	112	276.4	2.47
Large (2.1–2.5 mm.)	39	127.45	3.27

RELATION BETWEEN DIAMETER OF CONDUCTING TISSUE AND WEIGHT OF SPURS, FROM LIMBS HAVING A LIGHT BLOOM AND FROM THOSE HAVING A FULL BLOOM

As previously shown, the percentage of fruit set on limbs with relatively few flower-bearing spurs is greater than on limbs with an abundant bloom. It has been seen that heavy spurs have a greater tendency to set fruit than weak spurs, and that there is a relation between the weight of the spur and the diameter of the conducting cylinder in the spur. Are the spurs on limbs with a light bloom, heavier and more vigorous than the spurs on limbs with a full bloom? If so, is the conducting tissue of greater diameter in the former spurs than in the latter? These questions are answered by the data in table 28. Lot 1 consisted of all flower-bearing spurs from a limb on a Baldwin tree, and lot 2 of spurs from limbs on an Autumn Strawberry tree. Only twenty-five spurs from the limbs with a full bloom, and twenty-five from the ones with a light bloom, were considered in the latter case.

TABLE 28. RELATION BETWEEN DIAMETER OF CONDUCTING TISSUE AND WEIGHT OF SPURS, FROM LIMBS HAVING A LIGHT BLOOM AND FROM THOSE HAVING A HEAVY BLOOM

Lot	Relative diameter of conducting tissue	Spurs from limbs with a light bloom		Spurs from limbs with a heavy bloom	
		Number of spurs	Average weight (grams)	Number of spurs	Average weight (grams)
1	Small (1–1.5 mm.)	7	2.06	49	1.50
	Medium (1.6–2 mm.)	34	3.09	56	2.37
	Large (2.1–2.5 mm.)	14	4.01	20	3.10
	Total	55	3.20	125	2.16
2	Small	5	1.84	7	1.44
	Medium	16	2.53	11	2.39
	Large	4	3.38	7	2.63
	Total	25	2.53	25	2.19

The figures show that limbs with a light bloom have heavier spurs than limbs with a heavy bloom, and that spurs with conducting tissue of a given diameter taken from the former limbs weigh more than spurs with conducting tissue of the same diameter taken from the latter limbs. The leaves produced on spurs from limbs with a light bloom have a noticeably greater area than those produced on spurs which have conducting tissue of equal diameter but which were taken from limbs with a heavy bloom. The average leaf surface of several equally vigorous spurs obtained from these two sources was 125.34 and 86.51 square centimeters, respectively. The leaf area was measured by a planimeter.

RELATION BETWEEN WATER SUPPLY, LEAF AREA, AND PUSHING OF BUDS

It is generally understood that an abundant supply of water is a factor in producing large leaves. This was demonstrated by the following simple experiment. A number of dormant apple twigs were divided into two similar lots. The cut ends of the twigs were placed in beakers containing water. In one lot the cuts were renewed every few days and in the other lot they were renewed only seldom. The leaves of the former twigs were noticeably larger than those of the latter. This difference in size may be ascribed to the more abundant water supply obtained by the leaves on the twigs that had their cut ends frequently renewed.

A more elaborate experiment, which involved the forcing of water into the cut ends of the twigs, likewise indicated that there was a relation between the leaf surface and the water supply. The details of the apparatus used for this demonstration are shown in fig. 5. Tompkins King branches from three to four years old and approximately one meter long were used. The leaves on the twigs that had water forced into their bases were distinctly larger than those on untreated twigs.

This experiment, which was carried on in duplicate and which was repeated several times, yielded other results that may be of interest at this point. The buds on the check twigs, which were standing in a jar of water, opened about a week before the buds on the twigs that received their water supply under pressure. The first buds to open on the latter twigs were the small ones on relatively weak spurs. The first vigorous buds to push were those nearest the tops of the twigs. Droplets of sticky material oozed from all of the larger buds, which were found at the end of several centimeters of the previous season's growth. Similar exudations were observed on less vigorous buds produced on spurs arising near the bases of the twigs.

Apparently the delay in the pushing of buds was caused by excessive water pressure. The resistance encountered by the water passing thru a meter of conducting tissue of the twig was apparently sufficient to reduce the pressure to a point at which bud-pushing could occur; hence, the first vigorous buds to open were those nearest the tops of the twigs. Weak spurs apparently offered greater resistance to the passage of water; hence, they pushed first because they were not over-supplied with water.

It has been shown previously that vigorous, heavy spurs are usually provided with conducting tissue of comparatively large diameter. This experiment shows that the large, plump buds which produce the heavy spurs are more abundantly supplied with water than the smaller buds.

The difference in leaf area between the vigorous and the weak spurs is probably due, in part at least, to the difference in water supply, or, more accurately, sap supply. The vigorous spurs have larger leaves than the weak spurs

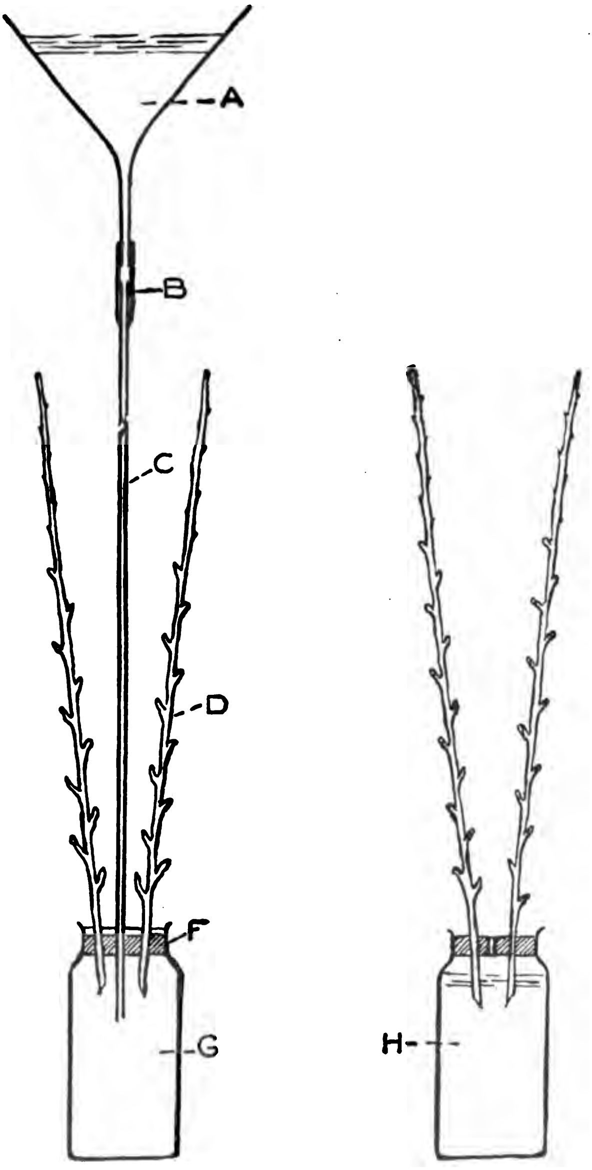

FIG. 5. APPARATUS FOR FORCING WATER INTO THE ENDS OF TWIGS

The pressure is supplied by a column of water three meters long. This column is maintained at approximately the same level by the water in the funnel, A, which is connected to the tube, C, by the union at B. The tube passes thru the cork, F. This cork is also provided with holes for the twigs, D. The twigs are from three to four years old and about one meter long. After these twigs and the tube have been inserted, the bottle, G, is filled with water. The cork is then flooded with warm paraffin. After this has become firm the pressure is applied. Check twigs are placed in the bottle H because they have a greater diameter of conducting tissue and hence can obtain more sap.

It has been seen that the leaf area for spurs which have a conducting tissue of a given diameter and which were taken from limbs producing many flowers, is less than that for spurs with the same diameter of conducting tissue but taken from limbs producing few flowers. If the size of the leaves is an indication of the supply of sap that reaches the spur, it must be assumed that the former spurs are not so abundantly supplied as the latter even tho they have conducting tissue of the same diameter. It probably requires greater sap pressure to expand mixed buds, which contain both flowers and leaves, than is needed to push leaf buds. Moreover, the petals of the flowers will transpire considerable moisture. It seems reasonable, therefore, to assume that limbs producing a heavy bloom will supply less sap to the individual spur than similar limbs which produce a light bloom. The spurs from the former limbs are not so likely to set fruit as those from the latter limbs. Can this be due to an inadequate supply of sap?

RELATION BETWEEN AMOUNT OF LATERAL GROWTH FROM THE FLOWER-BEARING SPUR, AND FRUITFULNESS OF THE SPUR

The elongation of a spur that is producing flowers is dependent on the pushing of at least one lateral bud found on the current season's spur growth (fig. 1, page 51). In a few spurs the setting of a fruit inhibits the formation of a lateral bud. In some cases lateral buds are formed, but they do not push until the following year; in other cases, as much as twenty-five centimeters lateral growth is produced by the fruiting spur. All gradations between these extremes are found. The lateral growth may begin even before the flowers have opened, and by the time the fruit sets such growth may be several centimeters long. Observations here showed that fruit-setting on spurs that had made from five to ten centimeters of lateral growth was not uncommon. In fact it appeared that only a relatively small proportion of such spurs lost their fruit.

The amount of lateral growth produced by setting and by non-setting spurs derived from the same limb was recorded in several cases. Data for a Baldwin limb are given in table 29. It is seen that fruit is borne on spurs that produce much lateral growth as well as on those that produce little growth. The average weight of the lateral growth is greater in the spurs that bear fruit than in those that lose their fruit.

In other cases, the lateral growth produced by spurs taken from limbs that bore many fruits and from similar limbs that bore few fruits, was

TABLE 29. LATERAL SPUR GROWTH PRODUCED BY SETTING AND BY NON-SETTING SPURS FROM A BALDWIN LIMB

Amount of lateral growth	Produced by setting spurs	Produced by non-setting spurs
No growth	6	10
2 leaves	20	13
3 leaves	20	14
4 leaves	5	5
5 centimeters	1	0
Average weight of lateral growth	1.35 grams	0.79 gram
Average weight of spurs minus lateral growth	2.39 grams	1.31 grams

carefully examined. The results obtained with a pair of similar limbs from a Strawberry tree are recorded in table 30. One hundred of the largest spurs from each limb are considered.

TABLE 30. LATERAL GROWTH PRODUCED BY LARGE FLOWER-BEARING SPURS, FROM LIMBS SETTING FEW AND FROM THOSE SETTING MANY FRUITS

Amount of lateral growth	Produced by spurs from limbs setting few fruits	Produced by spurs from limbs setting many fruits
2 leaves	24	12
3 leaves	42	23
0.5–5 centimeters	29	34
5.1–10 centimeters	5	7
10.1–20 centimeters	0	10
Over 20 centimeters	0	14
Average weight of lateral growth	1.91 grams	3.70 grams

According to the table, the spurs from the fruitful branches have a tendency to produce more lateral growth than those from the less fruitful limbs. The average weight of the lateral growth produced by the former spurs is almost double that produced by the latter.

These figures indicate that fruit-setting is not opposed by vegetative activity as manifested by the amount of lateral spur growth. On the contrary, they suggest that the conditions which favor such growth are likewise favorable for the setting of fruit.

One of the essential conditions for the forcing of the lateral buds is an abundant supply of sap. It is well known that heavy pruning of an apple tree during the dormant season stimulates the production of vigorous shoots from the remaining growing points. Such pruning disturbs the equilibrium between the top and the root systems, and as a result there is an abundant supply of food and water for vigorous top growth.

It should also be pointed out that the lateral buds on many flower-bearing spurs can be forced into growth by severe pruning of the branch that produces the spurs. It seems reasonable, therefore, to assume that such lateral spur growth is an indication of an abundant supply of sap.

RELATION BETWEEN SAP SUPPLY AND FRUIT SETTING

Several of the observations previously recorded have suggested that an adequate supply of sap to the individual spur is an important factor in the setting of fruit. The object of the following experiments was to determine whether the percentage of spurs that set fruit could be increased by increasing the sap supply, or decreased by reducing the sap supply, to the individual spurs.

In the spring of 1916, large limbs, which were approximately five centimeters in diameter at their bases and which had a full bloom, were selected in pairs. The members of such pairs either formed the arms of a Y or arose within a foot of each other from the same parent branch. It was necessary to have the limbs of a given pair as nearly alike as possible in vigor, exposure, bloom, and size, and for this reason the selection of suitable pairs was no easy task.

In several cases one limb of a pair was sawed halfway thru near its base, and the second limb was left untreated or was pruned lightly by cutting out entire twigs containing both weak and vigorous buds. In other cases one limb was left unpruned and not sawed at its base, while the second limb had at least half the total number of branches removed. The object of sawing the branches at the base was to diminish the normal sap supply to the spurs on the limbs so treated. The aim of the severe pruning was to increase the flow of sap to the individual buds. The treatments were given just before the flowers opened. The results are recorded in table 31:

TABLE 31. PERCENTAGE OF FLOWER-BEARING SPURS SETTING FRUIT ON LIMBS WITH INCREASED AND ON THOSE WITH DIMINISHED SAP SUPPLY

Lot	Variety	Limbs with normal or increased sap supply				Limbs with normal or diminished sap supply			
		Treatment of limb*	Number of spurs	Number set	Percentage set	Treatment of limb*	Number of spurs	Number set	Percentage set
1	Tompkins King	2	71	14	19.7	4	166	15	9.0
2	Tompkins King	3	71	22	31.0	1	111	25	22.5
3	Strawberry	2	350	131	37.4	4	682	139	20.4
4	Strawberry	2	767	226	29.5	4	1,445	344	23.8
5	Baldwin	3	112	36	32.1	1	143	31	21.7
6	Baldwin	4	177	61	34.5	1	184	38	20.6
7	Baldwin	4	46	40	87.0	1	45	19	42.2
8	Baldwin	2	119	82	68.9	4	145	77	53.1

*Treatments: 1, treated limb sawed at base; 2, treated limb severely pruned; 3, treated limb slightly pruned; 4, limbs untreated.

In all cases the limbs that received relatively little sap had a smaller percentage of fruit-setting spurs than those receiving an abundant supply of sap. In a case not recorded in the table, members of a pair of branches on a Strawberry tree were left untreated. One arm had 1064 flower-bearing spurs, and the other arm had 1155. The percentage of spurs setting fruit was 22 for the former and 22.2 for the latter. The untreated limbs in lots 3 and 4, table 31, produced fruit on 20.4 and 23.8 per cent, respectively, of their spurs. These figures would seem to indicate that the range of variation in the percentage set is only slight when large numbers of spurs are involved.

As previously shown, the lateral growth produced by a flower-bearing spur may be taken as an index to the sap supply to that spur. In order to determine whether the treatments given had the desired effect of increasing or decreasing the sap supply, the lateral spur growth was carefully examined in each case. The analyses of the lateral growth produced by fifty of the largest flower-bearing spurs from a pruned branch and an equal number from an unpruned branch of a Strawberry tree are recorded in table 32:

TABLE 32. LATERAL GROWTH PRODUCED BY FLOWER-BEARING SPURS FROM A PRUNED BRANCH AND FROM AN UNPRUNED BRANCH

Amount of lateral growth	Produced by spurs from pruned branch*	Produced by spurs from unpruned branch†
2 leaves	5	17
3 leaves	6	19
0.5–5 centimeters	31	10
5.1–10 centimeters	4	3
Over 10 centimeters	4	1
Average weight of lateral growth	2.68 grams	1.90 grams

* 37.4 per cent of the flower-bearing spurs produced fruit.
† 20.4 per cent of the flower-bearing spurs produced fruit.

The spurs from the pruned branch made a more vigorous lateral growth than those from the unpruned branch. This indicates that the pruning actually increased the amount of sap available for each spur on the treated branch. The observations made in the remaining cases showed that the limbs which set most fruit to the hundred spurs also produced the most vigorous lateral spur growth.

The percentages of large and of small spurs setting fruit on the limbs that received relatively little sap to the spur, and on those that received relatively much sap to the spur, are recorded in table 33. The spurs were classed as large if they were produced from buds that were terminal to one or more centimeters of the previous season's spur growth; if the spur growth was less than one centimeter, the spurs were classed as small.

TABLE 33. PERCENTAGE OF LARGE AND OF SMALL SPURS SETTING FRUIT ON LIMBS WITH DIMINISHED AND ON THOSE WITH INCREASED SAP SUPPLY

Lot	Variety	Large spurs			Small spurs		
		Diminished sap supply, percentage set	Increased sap supply, percentage set	Percentage gain	Diminished sap supply, percentage set	Increased sap supply, percentage set	Percentage gain
1	Tompkins King ..	25.0	26.1	1.1	6.8	16.6	9.8
2	Tompkins King ..	28.6	50.0	21.4	22.1	28.6	6.5
3	Strawberry.......	47.1	50.7	3.6	18.4	22.0	3.6
4	Strawberry.......	37.1	51.9	14.8	11.5	31.1	19.6
5	Baldwin.........	37.3	50.0	12.7	7.9	20.6	12.7
6	Baldwin.........	38.0	62.0	24.0	9.7	25.7	16.0
7	Baldwin.........	48.3	88.0	39.7	31.2	84.6	53.4
8	Baldwin.........	82.1	85.1	3.0	13.1	48.1	35.0

More fruit was produced on the large spurs than on the small spurs, as would be expected from previously recorded observations. The small spurs, as well as the large ones, are benefited by an increased supply of sap, as is indicated by the percentage gain.

The term *sap*, as used in the preceding paragraphs, has reference primarily to the watery solution taken up by the roots. No doubt some of the organic food stored in the roots, and in the trunk and the main limbs of the tree, would find its way into this solution before it reached the spur. It would be difficult to state definitely which was the more beneficial to the set of fruit — the water or the food material that it contained in solution. The fact that the vigorous spurs have a larger number of leaves and flowers than the weaker spurs, in itself suggests that the buds in which they were formed were well supplied with organic food. Müller-Thurgau (1898) has shown that many fruits are borne on limbs that have been girdled, while untreated limbs on the same tree with equally heavy blooms set relatively few fruits. Chandler (1913) has demonstrated that the sap derived from the cortex and the bark of girdled apple twigs is much denser than sap from similar limbs receiving no treatment. Gourley (1915) shows that more food is stored in fruiting than in non-fruiting spurs. There can be little doubt that an abundance of stored food is one of the factors favoring the setting of fruit. On the other hand, it must be borne in mind that heavy spurs usually have a large diameter of conducting tissue, which insures a good sap supply. Furthermore, the observations recorded above indicate that an abundant supply of sap to spurs inadequately provided with storage tissue increases the ability of such spurs to set fruit.

FRUIT SETTING AS INFLUENCED BY VARYING AMOUNTS OF LEAF SURFACE ON THE FLOWER-BEARING SPUR

As previously shown, limbs with small leaves have a smaller proportion of fruitful spurs than similar limbs with large leaves. The area of the leaf surface seems to be closely correlated with the vigor, or weight, of the spur, which in turn shows a relation to the diameter of the cylinder of conducting tissue thru which the sap reaches the developing spur. The leaves might have several effects: they might assist in drawing water to the spur — the "pulling power of transpiration"; they might provide increased nourishment for the developing tissue; they might prove detrimental during conditions favoring incipient drying, by actually withdrawing moisture from the young flower or fruit. (Chandler, 1915). In order to gain some information regarding the influence of the bud leaves on the setting of fruit, the following experiments were carried out:

In the first experiment, a number of pairs of similarly located and equally vigorous spurs were selected. The vigor of the spurs was determined by the amount of leaf surface, and also by noting the length of the previous season's growth. The spurs of each pair were taken from the same parent branch and from points within a few inches of each other. Vigorous spurs only were selected because previous observations had shown that such spurs have the greatest tendency to set fruit. The importance of having spurs of similar location and vigor is obvious.

One spur of each pair was entirely defoliated, while the other served as a check, receiving no treatment. The leaves on the former were removed just before the blossoms opened in the spring of 1916. The set of fruit on the spurs was determined during the latter part of August. Unfortunately, many pairs had to be discarded because of aphid injury. Only healthy spurs were considered. The data are recorded in table 34.

The figures indicate that some of the defoliated spurs bear fruit, but the percentage of these is very much less than in the case of normal spurs. The high percentage of fruitful spurs recorded for the latter class reflects the influence of vigor.

The object of the next experiment was to determine the effect of partial and of complete defoliation of flower-bearing spurs on the setting of fruit. Several lots, each consisting of three similarly located and equally vigorous spurs, were selected. As a rule, vigorous spurs have from seven to ten first, or bud, leaves. One spur in each lot served as a check; the

TABLE 34. PERCENTAGE OF NORMAL AND OF DEFOLIATED SPURS BEARING FRUIT

Variety and tree	Normal spurs			Defoliated spurs		
	Total number	Number set	Percentage set	Total number	Number set	Percentage set
Baldwin, 1	16	14	87.5	16	6	37.5
Baldwin, 2	11	11	100.0	11	6	54.5
Baldwin, 3	32	23	71.9	32	12	37.5
Total	59	48	81.4	59	24	40.7
Tompkins King, 1	42	23	54.8	42	2	4.8
Tompkins King, 2	52	19	36.5	52	5	9.6
Tompkins King, 3	43	23	53.5	43	10	23.3
Total	137	65	47.4	137	17	12.4

second spur had all but two leaves removed; the third spur was entirely defoliated. The defoliation was done before the flowers opened in the spring of 1916. The set of fruit was determined during late August. Again many spurs were infested with aphids and had to be discarded. The data are recorded in table 35:

TABLE 35. PERCENTAGE OF NORMAL, OF PARTIALLY DEFOLIATED, AND OF COMPLETELY DEFOLIATED SPURS SETTING FRUIT

Variety	Normal spurs			Spurs with all but two leaves removed			Defoliated spurs		
	Total number	Number set	Percentage set	Total number	Number set	Percentage set	Total number	Number set	Percentage set
Baldwin	32	23	71.9	32	22	68.8	32	12	37.5
Tompkins King	51	19	37.3	52	18	34.6	52	5	9.6
Total	83	42	50.6	84	40	47.6	84	17	20.2

The figures show that spurs with two leaves set approximately as well as spurs with all leaves. The presence of a small amount of leaf surface apparently offsets the harmful effects of entire defoliation.

Many spurs set more than one fruit. The percentage of such spurs in defoliated and in check lots is given in table 36. The normal spurs, as might be expected, are more likely to produce two fruits than are defoliated spurs. The percentage of spurs setting more than one fruit is three times as great in the case of the untreated spurs as in the defoliated lot.

TABLE 36. NUMBER OF FRUITS TO THE SPUR ON NORMAL AND ON DEFOLIATED SPURS

Number of fruits to the spur	Number of spurs with respective number of fruits	
	Normal spurs	Defoliated spurs
1	35	21
2	19	3
3	4	0
Percentage of spurs setting more than one fruit	39.7	12.5

These results are interesting because they show that a small leaf surface in itself, such as is found on spurs on weak limbs or on those with a heavy bloom, is not accountable for a poor set of fruit. The data at hand do not afford an adequate explanation for the results obtained. On the basis of observations and experiments presented later, however, it seems reasonable to assume that the leaves favor fruit-setting on vigorous spurs because they assist in drawing sap to the fruit.

INFLUENCE OF SUNLIGHT ON THE SETTING OF FRUIT

In order to learn whether or not a variety is self-sterile, cross-pollination is prevented by inclosing the flower spurs in sacks. According to Ewert (1907), such treatment subjects the inclosed spurs to unnatural conditions which may be unfavorable for the setting of fruit. The object of the following experiments was to determine the effect of excluding sunlight on the setting of fruit.

Some vigorous spurs were inclosed in brown opaque paper bags, and some in white translucent paper bags. Only the most vigorous spurs were inclosed, and for each spur inclosed in a translucent sack a similar spur arising from the same parent branch was inclosed in an opaque sack. The spurs were sacked in the spring of 1916, before the clusters of flowers had separated. The set of fruit was determined in late summer. Unfortunately a large number of the sacked spurs had to be discarded because of aphid work. The data obtained, however, are very suggestive. They are recorded in table 37, in which it is seen that over twice as many spurs set fruit in the translucent sacks as in the opaque sacks.

The following notes may be of interest: On May 17, 1916, the flowers in the opaque bags had white petals, and all flowers in the cluster were open; the flowers in the translucent bags had pink petals, and were somewhat further advanced than the flowers in exposed clusters. The stigmas

TABLE 37. SET OF FRUIT ON SPURS INCLOSED IN OPAQUE BAGS AND ON SPURS INCLOSED IN TRANSLUCENT BAGS

Variety	Branch	Spurs inclosed in opaque bags			Spurs inclosed in translucent bags		
		Total number	Number set	Percentage set	Total number	Number set	Percentage set
Baldwin..........	1	25	7	28.0	25	11	44.0
Baldwin..........	2	19	3	15.8	19	14	73.7
Total.........	......	44	10	22.7	44	25	56.8

on all inclosed flowers were green; those on exposed flowers had a reddish tinge, even before the petals unfolded. The leaves on all the inclosed spurs were smaller than those on the exposed spurs. At the time when the fruit-setting spurs were counted, it was observed that there was a tendency for fruit in the translucent sacks to attain the June-drop size before it fell, whereas in the opaque sacks the fruit fell when very small. All the flowers in the experiment were self-pollinated if pollinated at all.

The figures indicate that exposure to sunlight is an added advantage in fruit setting. The results agree with those of Lubimenko (1908), who finds that illumination is essential during the early stages of development of young fruit.

Inclosing the spurs in bags inhibits the free circulation of air, and transpiration is probably reduced as a result. The air temperature in the brown bags would be higher than that in the white bags on sunny days. The diffused light in the translucent sacks would be sufficient for some photosynthetic activity, while practically all light is excluded from the opaque sacks. The leaves in the former, being exposed to light, would probably have greater osmotic properties than those in the dark (Chandler, 1913). The advantage of having leaves with the greater osmotic properties would be that more sap would tend to flow in the direction of the spurs which produce such leaves. This sap would be available for the setting of fruit.

RELATION BETWEEN SEED FORMATION AND FRUIT DEVELOPMENT

It is commonly supposed that the apples which are poorly fertilized and which consequently develop few seeds, tend to fall off during the June drop. That there is a close relation between seed formation and fruit development is shown in the following paragraphs.

Number of seeds in fruit that sets and in fruit that drops

The drop apples have fewer seeds on the average than are found in the average fruit that remains on the tree, as shown by the representative data in table 38:

TABLE 38. AVERAGE NUMBER OF SEEDS IN FRUIT THAT DROPS AND IN FRUIT THAT REMAINS ON THE TREE

Variety	Drop fruit		Attached fruit	
	Number of fruits	Average number of seeds to the fruit	Number of fruits	Average number of seeds to the fruit
Baldwin	48	3.38	47	4.47
Rhode Island	66	3.51	29	6.43
Maiden Blush	65	3.94	66	6.28

The number of seeds found in individual fruits that have fallen and in individual fruits taken from the tree are given in table 39. The column on the left contains the number of seeds to the fruit. The figures in the other columns give the number of fruits showing the respective number of seeds. It is seen that many attached fruits have relatively few seeds and some drops have a high seed content. This suggests that other factors, in addition to fertilization or pollination, are responsible for the set of fruit.

TABLE 39. NUMBER OF SEEDS IN FRUIT THAT DROPS AND IN FRUIT THAT REMAINS ON THE TREE

Number of seeds to the fruit	Baldwin		Rhode Island		Maiden Blush	
	Attached fruit	Drop fruit	Attached fruit	Drop fruit	Attached fruit	Drop fruit
1	......	2	......	6	1	3
2	5	16	......	13	4	17
3	9	12	4	18	9	17
4	9	7	1	9	7	8
5	14	4	5	15	4	6
6	6	6	5	2	10	7
7	3	0	5	1	10	3
8	1	1	6	2	11	4
9	......	......	1	......	6	......
10	......	......	1	......	2	......
11	......	......	1	......	0	......
12	......	......	......	......	1	......
13	......	......	......	......	1	......

Osterwalder (1907 a) examined the seeds in fruit that had fallen from the tree. He found that sixty-five per cent of these contained embryos, while about seventy-five per cent of the seeds in the fruit that remained on the tree contained embryos.

Relation between number of seeds and size of fruits

Müller-Thurgau (1898) has studied the relation between the number of seeds and the size of berry in the grape. For eighteen varieties of grapes he finds the following averages:

Weight of flesh of 100 seedless grapes, 42.8 grams
Weight of flesh of 100 1-seeded grapes, 144.0 grams
Weight of flesh of 100 2-seeded grapes, 209.3 grams
Weight of flesh of 100 3-seeded grapes, 253.9 grams

He also presents data indicating that a similar relation exists in the case of apples and pears, and his results are substantiated by Ewert. The general law, that the more are the seeds the larger is the apple, is illustrated by the figures in table 40. These data were obtained in 1915 from trees in the experiment station orchard at Cornell.

TABLE 40. NUMBER OF SEEDS AND SIZE OF FRUITS

Number of seeds to the fruit	Maiden Blush		Baldwin	
	Number of fruits	Average diameter (millimeters)	Number of fruits	Average weight (grams)
1	2	8.0	2	2.98
2	16	10.5	4	3.27
3	27	11.9	5	3.60
4	10	13.2	11	4.84
5	5	14.6	5	5.47
6	6	16.8	9	6.53
7	3	17.7	....	....
8	2	19.8	....	....
9	2	19.0	....	....

This relation, being based on averages, will naturally not cover all cases. During preliminary observations, few-seeded apples were found which were as large as many-seeded fruits, and not infrequently even larger. Further study showed that in a number of cases the relatively small fruit with many seeds was associated with a small spur. This suggested that the vigor of the spur, as determined by its weight, might be a factor, together with the number of seeds, in determining the size of the fruit. Accordingly, accurate weights of several hundred spurs, together with the weight of the fruit borne on these spurs and the number of seeds contained in each fruit, were recorded. The weighings were made during July of 1915 and July of 1916. The data obtained in this way are analyzed from several points of view in the following paragraphs.

Size of fruit constant, number of seeds varying.— In the cases recorded in table 41, the fruits in each lot are approximately constant in weight but the number of seeds varies. It should be mentioned that the fruits in each lot were produced on the same branch. The branches were approximately ten years old and measured about one and one-half centimeters in diameter at their bases.

TABLE 41. WEIGHT OF FRUIT CONSTANT, NUMBER OF SEEDS AND WEIGHT OF SPURS VARYING

Lot	Variety	Weight of fruit (grams)	Number of seeds to the fruit	Weight of spurs (grams)
1	Tompkins King	14.95	2	5.54
		14.72	4	5.05
		14.86	6	2.31
		13.30	7	1.98
2	Tompkins King	16.05	2	3.97
		16.96	6	1.45
3	Tompkins King	30.96	3	6.09
		31.68	6	3.75
4	Tompkins King	95.90	2	5.05
		97.10	4	2.40
5	Rhode Island	25.58	3	4.86
		25.31	8	2.28
6	Westfield	21.64	5	2.33
		21.87	8	1.31

If the weights of the spurs that bore the few-seeded fruits are compared with the weights of those that bore the many-seeded fruits, it is seen that in all cases the vigor was greater in the spurs bearing the few-seeded fruits. In other words, the smaller the spur, the greater is the number of seeds required to produce a fruit of a given size.

Weight of spur constant, number of seeds varying.— The weight of spurs in each group is approximately constant in the cases recorded in table 42. The number of seeds in the fruits borne by these spurs varies. In each lot, as before, the spurs were produced on the same parent branch.

TABLE 42. WEIGHT OF SPUR CONSTANT, NUMBER OF SEEDS AND WEIGHT OF FRUIT VARYING

Lot	Variety	Weight of spur (grams)	Number of seeds	Weight of fruit (grams)
1	Tompkins King	4.76	1	12.87
		4.65	5	26.80
2	Tompkins King	3.38	1	8.53
		3.40	5	20.78
3	Tompkins King	3.51	2	12.77
		3.53	9	20.08
4	Tompkins King	1.54	2	6.37
		1.60	6	13.76
5	Tompkins King	4.31	2	86.10
		4.34	4	103.00
6	Tompkins King	4.87	2	84.20
		4.90	5	112.70
7	Tompkins King	3.41	4	38.31
		3.40	7	50.88
8	Tompkins King	4.60	2	23.55
		4.90	5	43.87
9	Baldwin	2.47	3	16.28
		2.47	6	23.73
10	Baldwin	3.47	2	45.80
		3.55	5	58.60
11	Baldwin	2.48	3	47.60
		2.47	5	60.40
12	Baldwin	4.51	3	39.40
		4.56	6	60.00
13	Baldwin	3.75	3	31.97
		3.74	7	42.84
14	Baldwin	3.63	3	35.25
		3.61	5	40.12
15	Baldwin	2.34	3	15.72
		2.43	7	21.01
16	Westfield	2.28	3	16.84
		2.24	5	18.72
		2.21	8	23.15
		2.26	9	24.02
		2.22	11	29.40
17	Fallawater	1.64	2	26.13
		1.65	5	35.97

The data show that when the weight of the spur is constant, the size of the fruit varies with the number of seeds. In other words, the size of the fruit is determined chiefly by the vigor of the spur and the seed content of the fruit.

Weight of spur constant, number of seeds constant, size of embryo varying.—Theoretically, according to one interpretation of the above hypothesis, if spurs of approximately equal vigor are chosen which bear fruits containing the same number of seeds, the fruits borne on these spurs should be approximately equal in weight. Or, stated in a different way, if the fruits vary in size while the seed number remains the same in each, a difference would be found in the vigor of the spurs producing these fruits, and furthermore one would expect to find the largest apple on the most vigorous spur. That these theoretical results are not always obtained may be seen from the examples in table 43:

TABLE 43. WEIGHTS OF FRUITS HAVING THE SAME NUMBER OF SEEDS, AND WEIGHTS OF THE SPURS THAT BEAR THE FRUITS

Lot	Variety	Number of seeds	Weight of fruit (grams)	Weight of spur (grams)
1	Baldwin	4 4	6.37 6.24	4.28 3.20
2	Baldwin	4 4	5.12 5.07	3.55 1.90
3	Tompkins King	6 6	41.90 29.86	2.54 2.59

These data seem to disprove the existence of a direct relation between size of fruit, vigor of spur, and number of seeds. The emphasis, however, is to be placed on seed content rather than mere number of seeds.

In studying the seeds, one cannot help noticing marked differences in the size of the seeds in given fruits. The embryos in the seeds likewise show considerable variation. The embryo is readily dissected from the seed by placing the seed flatwise between the thumb and the forefinger, with the lateral edge upward, cutting the edge with a sharp scalpel, and pressing the embryo out of the seed coat.

In several cases the number of embryos found in the seeds of a given fruit and the length of the individual embryo were recorded, along with the weight of the fruit and the weight of the spur on which the fruit was borne. These data are given in table 44. The figures under the column headed *Length of embryo* show the number of seeds in each fruit and the length in millimeters of the embryo in each seed; for example, 6–5–5 indicates that the fruit contained three seeds, which in turn contained embryos measuring six, five, and five millimeters, respectively. The fruits in the different lots are arranged in order of their weight. The weights of the spurs bearing the fruit are also given. The fruits in each lot were produced on the same branch.

TABLE 44. WEIGHT OF FRUIT, WEIGHT OF SPUR, AND LENGTH OF EMBRYO

Lot	Variety	Weight of fruit (grams)	Weight of spur (grams)	Length of embryo (millimeters)
1	Tompkins King	77.00	3.60	6–5–5
		69.00	5.68	7–7–5
		68.25	6.12	7–5–3
		65.31	6.71	5–5–5
		52.20	2.45	7–7–6
2	Baldwin	37.58	4.55	7–7–7
		35.25	3.63	7–4–2
		33.95	3.53	7–5–2
		33.72	3.16	7–6–6
		31.97	3.75	7–3–3
		30.86	2.93	7–7–3
		30.11	3.85	6–5–3
		26.42	2.62	7–6–3
3	Baldwin	42.84	3.76	8–7–7–7–6–4–1
		41.84	6.06	8–7–6–5–3–1–0
		41.71	3.14	8–7–6–6–6–4–2
		40.28	3.43	7–7–7–5–4–4–1
		38.13	1.97	9–8–7–7–6–3–3
		35.63	3.48	7–7–7–5–5–1–1

The data show that in most cases the size of the fruit can be accounted for by taking into consideration the weight of the spur and the length of the embryos in the seeds. The fruit with the longest embryos will usually be the heaviest if it is borne on the most vigorous spur. A fruit may attain a good size on a relatively small spur if its seeds contain large embryos. Conversely, a small fruit borne on a large spur is the result of a small embryo.

In this connection it should be noticed that a small spur may produce a large fruit, and a large spur a relatively small fruit. These facts afford additional evidence to show that the weight of the spur is not markedly influenced early in the season by the fruit borne on it.

That exceptions are found to the general rule is not surprising. One could hardly expect that a single measurement would tell all about the possibilities of the embryos for fruit formation. Some embryos are plumper than others even tho they are of the same length. Some have different shapes. Furthermore, they vary in color, some being ivory white, others yellowish, others hyaline in appearance. All this suggests a difference in quality, such as might result from cross-pollination, for example.

Number of seeds and seed value.— As shown above, the seed value as expressed by the length of the embryo may vary in the different fruits even tho the number of seeds is the same. It is entirely possible that a many-seeded fruit may have a seed value which is below the normal for that number. It may be equal to, and in some cases even less than, the seed value of a fruit with few seeds. Such an assumption is borne out by the fact that in a large number of three-seeded Baldwin fruits, seventy per cent of the embryos were above medium length — five millimeters — while in many-seeded fruits of the same variety only about fifty per cent of the embryos were large. If the ratio of the weight of the spur to the weight of the fruit is greater in a few-seeded fruit than in a many-seeded fruit borne on a similarly located spur of equal weight, one would be justified in assuming that the seed value of the latter fruit was below normal. A specific case may be taken for example as follows:

Number of seeds	Weight of spurs (grams)	Weight of fruit (grams)
2	2.05	49.1
5	2.00	44.3
5	2.00	62.7

These spurs were borne on the same twig and they produced their fruits under similar external conditions so far as could be seen. Obviously, the five-seeded fruit that weighs only 44.3 grams has a seed value below normal. This seed value is equivalent to that of a few-seeded fruit. There may be found a fruit weighing less than 49 grams which nevertheless has a high seed value. Such a fruit, however, would be on a spur weighing less than two grams; thus, a fruit with four seeds, weighing 35.5 grams, was produced on a spur that weighed one gram.

It therefore becomes necessary to modify the general statement that the size of fruit is proportional to the number of seeds. It would be more nearly accurate to say that the vigor of the individual spur and the seed value of the individual fruit determine the size of the fruits derived from the same limb and borne under otherwise similar conditions. This statement includes the prominent part played by the spur, and it also emphasizes seed value rather than number of seeds. It is, of course, very necessary to choose spurs borne under otherwise similar conditions, as is shown later.

Relation between seed value, weight of spur, and set of fruit

That the vigor, or weight, of the flower-bearing spur is an important factor in determining whether the flowers will set fruit, has been suggested by data previously recorded. Figures have likewise been presented which show that the drop apples contain fewer seeds than the fruit that remains on the tree. This indicates that the number of seeds, which presupposes effective pollination, likewise plays a part in determining the set of fruit.

Since, then, the smaller spurs are more likely to lose their fruit than the larger, and since the average number of seeds is less in the drops than in the setting fruit, it is apparent that most of the few-seeded drops were borne on small spurs.

But, as has been shown, there are many fruits that remain on the tree even tho they have few seeds — less in some cases than are found in the average fruit that has dropped. According to the statements in the preceding paragraph, these few-seeded fruits would have fallen if they had been borne on relatively light spurs. Therefore it must be assumed that they were produced on vigorous spurs. Since relatively few fruits with many seeds are found among the drops, and since there is no basis for assuming that the flowers on less vigorous spurs will necessarily be poorly pollinated and hence develop few seeds, one might expect to find fruit with many seeds on relatively weak as well as on vigorous spurs. To account for the drops with many seeds it must be assumed, in order to be consistent, that these came from very weak spurs. Then, too, they might have a low seed value even tho their seed number is high.

Stating this hypothesis in other words, few-seeded fruits, or, more accurately, fruits with a low seed value, are borne only on the heavier spurs, while many-seeded fruits, or those with a high seed value, may be borne on relatively light as well as on vigorous spurs.

In order to test this hypothesis, the weights of several hundred spurs, together with the weights of the fruits borne on them and the number of seeds in each fruit, were obtained during late July and early August. The weight of spur includes all of the present season's growth minus the lateral growth. The spurs were cut from the twig in the manner previously described (page 67). The spurs obtained from each twig or branch were divided into two lots, one containing the fruits with a high seed value and the other including the fruits with a low seed value. The determination of the seed value of a fruit was based on the observations regarding the relation between number of seeds, vigor of spur, and size of fruit. These observations also afforded the suggestions for the study of the relation between number of seeds, size of spur, and set of fruit. The results are recorded in table 45:

TABLE 45. WEIGHTS OF SPURS BEARING FRUIT WITH A LOW SEED VALUE AND OF THOSE BEARING FRUIT WITH A HIGH SEED VALUE

Lot	Variety	Fruits with a low seed value			Fruits with a high seed value		
		Number of spurs	Average weight of spurs (grams)	Average weight of fruit (grams)	Number of spurs	Average weight of spurs (grams)	Average weight of fruit (grams)
1	Baldwin	24	3.46	20.33	17	2.73	46.39
2	Baldwin	14	3.56	30.94	8	2.73	39.08
3	Baldwin	16	3.91	33.28	27	2.64	34.25
4	Baldwin	25	3.12	48.29	19	3.00	56.52
5	Baldwin	12	3.56	20.11	8	2.60	23.81
6	Fallawater	33	2.58	26.19	16	2.46	35.79
7	Rhode Island	15	4.33	23.89	13	4.39	31.16
8	Tompkins King	7	3.95	26.62	3	2.36	31.30
9	Tompkins King	6	4.49	28.72	7	5.02	42.93
10	Tompkins King	10	4.44	49.29	5	2.61	51.41
11	Tompkins King	10	4.78	65.06	5	2.61	67.30
12	Tompkins King	18	4.25	55.92	10	4.10	122.50
13	Tompkins King	32	2.92	13.80	19	2.05	16.78
14	Tompkins King	32	3.33	15.15	20	3.27	19.58
15	Westfield	24	2.43	19.19	20	2.25	25.15
	All varieties	278	3.41	....	197	2.90	....

It is seen that in practically all cases the spurs bearing fruits with a low seed value are heavier than those bearing fruits with a high seed value. In the average of all varieties, the spurs bearing fruits with a low seed value are 17.6 per cent heavier than those bearing fruits with a high seed value. There is no apparent reason why a vigorous spur should not bear fruit with a high seed value, hence it is not surprising that individual lots, such as numbers 7 and 9, should show heavier spurs for many-seeded than for few-seeded fruits. When the average weight of spurs for a lot in which the fruit has a low seed value is approximately the same as for the fruit from the same branch with a high seed value, the weight of the fruit in the latter case is considerably greater than in the former; this is shown by lots 4, 6, 7, 12, and 14. In those cases in which the fruits are almost of the same weight for many-seeded and for few-seeded lots, such as lots 3, 10, and 11, the spurs in the latter are the heavier.

In table 46 only half of the total number of spurs are considered — that half containing the smaller spurs. In this table the differences before noted are more marked because of the elimination in each class of the half containing the heavy spurs. The smaller spurs bearing fruit with a low seed value are 28 per cent heavier than the smaller spurs bearing fruit with a high seed value.

TABLE 46. WEIGHTS OF SMALLER SPURS BEARING FRUIT WITH A LOW SEED VALUE AND OF THOSE BEARING FRUIT WITH A HIGH SEED VALUE

Variety	Fruits with a low seed value		Fruits with a high seed value	
	Number of spurs	Average weight of spurs (grams)	Number of spurs	Average weight of spurs (grams)
Baldwin	12	2.45	9	1.80
	7	2.44	4	2.30
	8	3.28	14	2.03
	12	2.48	9	2.10
	6	3.00	4	2.18
Fallawater	17	1.89	8	1.24
Rhode Island	7	3.63	6	3.24
Tompkins King	3	3.17	2	2.24
	3	4.18	3	3.29
	5	3.49	3	2.00
	5	4.26	3	2.08
	9	3.29	5	3.01
	16	2.02	10	1.44
	16	2.58	10	2.25
Westfield	12	2.18	10	1.64
All varieties	138	2.65	100	2.07

A poorly fertilized flower can develop into a fruit, provided it is borne on a vigorous spur; a weak spur, on the other hand, will mature only a fruit that is developing many good seeds.

These data suggest that there is greater need for cross-pollination when the flowers are produced on trees growing under conditions that are unfavorable for the production of strong spurs, than for trees under favorable conditions. It is well known that apple trees growing in sod will usually produce less fruit than similar trees growing under cultivation. Do sod trees produce less vigorous spurs than cultivated trees, and consequently demand better fertilization of the flowers to insure a set of fruit?

The following observations may throw some light on this question. A large number of apples from a mature Tompkins King tree growing in sod contained an average of 6.1 seeds. Fruits from a tree of the same age and variety growing in a cultivated orchard had an average of 3.8 seeds. The orchards in question were about half a mile apart. In both, the opportunities for cross-pollination were good. It seems reasonable to suppose that the apples which dropped from the trees in the sod orchard contained more seeds to the fruit than the drops from the well-cared-for trees. In other words, the former trees required the stimulus of many seeds to set fruit, while the latter set fruit even tho few seeds were developed.

OBSERVATIONS CONCERNING SOME OF THE PHYSIOLOGICAL EFFECTS OF SEEDS

It has been shown that the size of the fruits borne on a given branch under certain external conditions is dependent on the vigor of the spur and the seed value. The higher the seed value, the larger is the apple under conditions otherwise similar. This suggests that the seeds exert some influence which increases the supply of sap to the fruit in which they are borne.

The heavier and more vigorous spurs, as previously shown, are provided with a large diameter of conducting tissue, which permits of more abundant sap flow. Large spurs that have good conducting tissue are able to set fruit with a low seed value, whereas the fruits on the smaller spurs must have a high seed value if they are to continue development. One might assume that the handicap of poor conducting tissue in the small spur is overcome by the pull on the sap flow exerted by the seeds. Small spurs require considerable help in order to provide an adequate supply of sap for a developing fruit, while large spurs need relatively little help. The following direct evidence is presented to show that many-seeded fruits actually do exert a greater pull on the sap flow than do few-seeded fruits.

Withdrawal of water by leaves from fruits with varying numbers of seeds

A number of spurs, each bearing one fruit, were taken from a branch of a Tompkins King tree in July, 1915. All but three of the leaves were removed from each spur, the leaves remaining being approximately of the same size and therefore the leaf surface on one spur being equal to that on any other. The fruits were coated with melted paraffin to prevent transpiration, and the spurs were then exposed in the laboratory. Some spurs without fruit and some detached fruits were exposed at the same time.

In conformity with the observations of Chandler (1914), the leaves on spurs that bore fruit remained turgid for several days, while the fruits on such spurs wilted and became shriveled. The leaves on spurs without fruit soon became dry and crisp. The detached fruits remained firm. That the leaves on the spurs bearing apples obtained their moisture from the fruit, is obvious. The point which is of special interest in this connection is that even tho the fruits were equally large in all cases, and even tho the leaf area was approximately the same on all spurs, some fruits remained firmer than others. The leaves on the spurs having the firm fruits dried before those on the spurs bearing the shriveled fruits. Examination showed that the badly shriveled fruits had fewer seeds than those which were comparatively firm. The greater the number of seeds, the less water was withdrawn from the fruit by the leaves.

In several cases the fruit had not shriveled uniformly, but one side remained firm while the other was decidedly wrinkled. In most cases of this nature, the shriveled side corresponded to a seedless cavity while the firm side usually contained two seeds in the corresponding cavity (fig. 6). Similar results were obtained in repeated experiments, altho exceptions to the general rule were occasionally found. Such exceptions might be explained on the basis of seed value. In these experiments it is essential to choose spurs that bear fruit under exactly similar conditions, as is emphasized later.

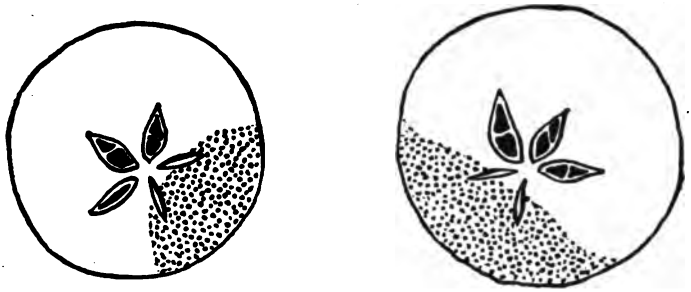

FIG. 6. CROSS SECTIONS OF APPLES, SHOWING THE RELATION BETWEEN SEEDS AND THE ABILITY TO WITHHOLD WATER

The dotted area indicates the wilted part. It is associated with the seedless cavities

Depression of freezing point by sap from fruits with varying numbers of seeds

As Chandler (1913) has shown, sap obtained from leaves freezes at a lower temperature than sap obtained from green fruit. The movement of sap from fruit to leaves is accounted for by osmosis. Since leaves withdraw water from many-seeded fruits less rapidly than from few-seeded fruits, one might expect that the sap from fruits with many good seeds would depress the freezing point more than sap from few-seeded fruits.

A few preliminary determinations regarding this point were made in August, 1915. The results obtained are very suggestive. The sap was expressed from apples whose seed content was known. A single apple did not yield sufficient sap, hence three or four fruits with the same number of seeds were used in each case. The apples were first ground up in a food chopper, and the sap was then expressed from the pomace. The freezing points of this sap were obtained by means of a Beckman apparatus. The results are given in table 47, which shows that the sap from fruits with few seeds depresses the freezing point less than does the sap from many-seeded fruits. It should be pointed out, in this connection, that these freezing points are for sap expressed from the live tissue of the fruits. If the tissue had been frozen before the sap was expressed the depression of the freezing point would no doubt have been greater in each case.

TABLE 47. DEPRESSION OF FREEZING POINT BY SAP FROM FRUITS WITH VARYING NUMBERS OF SEEDS

Variety	Sap from fruits with few seeds		Sap from fruits with many seeds	
	Number of seeds in fruit	Depression of freezing point (degrees centigrade)	Number of seeds in fruit	Depression of freezing point (degrees centigrade)
Tompkins King	2	1.081	6	1.119
Baldwin	2	1.123	6	1.153
Westfield	5	0.972	9	1.024
Fallawater	3	1.009	5	1.027
Baldwin	3	0.809	6	0.909
Rhode Island	3	0.900	5	0.967
Average	3	0.982	6.2	1.033

The average weight of the spurs and of the fruits is given, in connection with the number of seeds and the depression of the freezing point, in table 48. These data likewise indicate that the sap of many-seeded fruits is capable of developing a greater osmotic pressure than the sap from few-seeded fruits. This fact suggests why the many-seeded fruits do not lose water as readily as do the few-seeded fruits.

That the term *greater seed value* is more nearly accurate than *many seeds* is indicated by the last experiment in table 48. The eight-seeded fruits in this case have a lower seed value than the three-seeded fruits. As would be expected under such conditions, the three-seeded fruits show the greater sap density.

TABLE 48. DEPRESSION OF FREEZING POINT BY SAP FROM FRUITS WITH VARYING NUMBERS OF SEEDS, WEIGHTS OF SPURS, AND WEIGHTS OF FRUITS

Lot	Average weight of spurs (grams)	Average weight of fruit (grams)	Number of seeds	Depression of freezing point (degrees centigrade)
1	5.47	68.35	3	1.112
	2.11	68.53	5	1.152
2	5.12	86.40	4	1.112
	2.31	51.24	5	1.182
3	4.21	26.29	3	0.900
	4.32	25.62	8	0.867

Relation between formation of seeds and symmetrical development of fruit

It may be of interest in this connection to record observations regarding the symmetry of fruits. Müller-Thurgau and Ewert give figures in which the amount of flesh of the fruit is more or less proportional to its seed content. If the seeds are confined to one side of an apple, only that side will be fully developed while the other side will be much smaller. Such unsymmetrical development is found in a high proportion of the fruits that are lost during the June drop. Comparatively few of the normal apples — those free from insect, disease, and other blemishes — which remain on the tree are one-sided, altho mature fruits with one or more of their cavities seedless are frequently found. These observations can be explained in the following manner:

As has just been shown, fruits with many seeds, or with a high seed value, apparently have denser sap than few-seeded fruits. Such many-seeded fruits can therefore exert a greater pull on the sap flow. If the fruit is borne on a weak spur, the seeds play a very important part in obtaining sufficient food and water because the sap must pass thru a poorly developed conducting tissue. If a fruit with a seedless cavity happens to develop on a weak spur, the side without seeds suffers first and falls behind in growth. Sooner or later the poorly pollinated fruit on the weak spur drops, and hence many of the drops are one-sided.

Poorly pollinated fruit that remains on the tree is usually borne on vigorous spurs. Such spurs are generally provided with good conducting tissue which can supply abundant sap with comparatively little stimulation such as is afforded by seeds. The influence of the seeds in fruits developed on strong spurs is therefore only a secondary influence, and the presence or absence of seeds in one cavity of the fruit makes relatively little difference in the growth of the corresponding side of the apple (fig. 7). Fruits remaining on weak spurs after the June drop are normally well pollinated and generally develop seeds in all cavities; hence they too will be symmetrical.

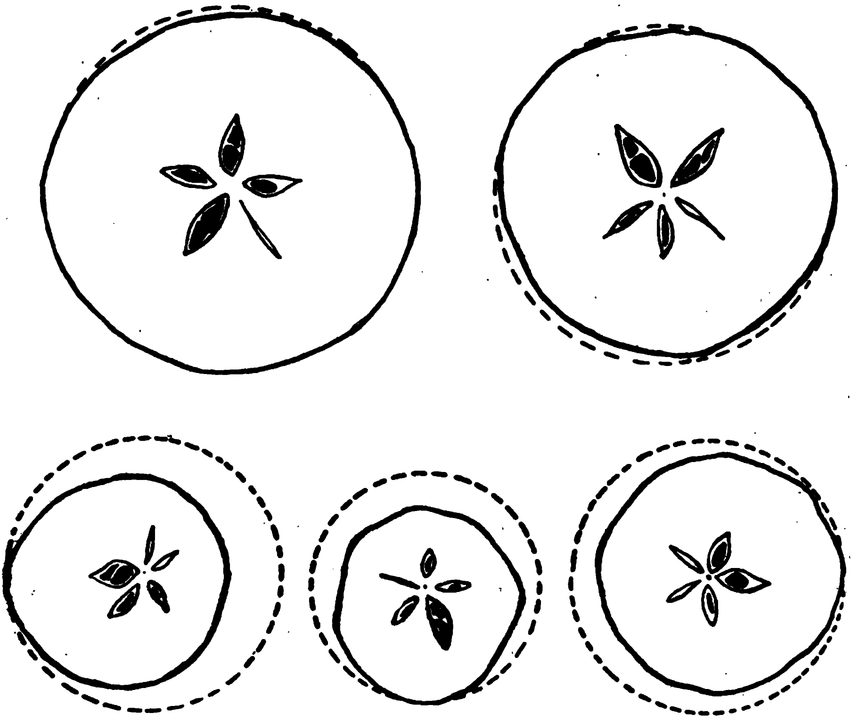

FIG. 7. CROSS SECTIONS OF APPLES THAT DROPPED AND OF THOSE THAT REMAINED ON THE TREE

The circles surrounding each section are drawn with the longest possible radius extending from the center of the core to the surface. The smaller apples are the June drops. In these the fruits fall behind in their development on the seedless side. In the apples remaining on the tree (the larger sections) asymmetry is not so closely correlated with the seedless cavity

RELATIONS TO BE CONSIDERED IN CHOOSING FRUITS BORNE UNDER SIMILAR CONDITIONS

As pointed out previously, it is very essential that fruits intended for study of the relations between size of fruit, number of seeds, and vigor of spur should be produced under exactly similar conditions. The following paragraphs suggest some of the things which must be kept in mind in choosing fruits suitable for this purpose.

Position of the fruit on the spur, and number of seeds to the fruit

The average apple spur bears five flowers. The central flower has the shortest stem and is usually the first to open in spring. In 1915 at the station orchard, practically all the fruits that developed came from central flowers; fruits from lateral flowers with long stems were exceptional. In 1916, on the other hand, comparatively few of the fruits had short stems. The reason for this is suggested by the following data, which were obtained just when the central flowers of the clusters were opening. The percentages are based on a consideration of all flower-bearing spurs borne on four large branches. There were over two hundred spurs.

Percentage of spurs apparently normal	16
Percentage of spurs with central flower abortive	58
Percentage of spurs with stamens and styles of central flower abnormal	26

The abnormal stamens were undersized, malformed, and whitish; the styles also were malformed and dwarfed. The leaves of the spurs producing abnormal central flowers were somewhat wrinkled when they first opened. No disease and no insects were present. For a time it was believed that the injury might have been due to the dormant spray which was applied after the leaves appeared, but unsprayed trees along the roadside showed the same injury as did sprayed trees. These abnormalities were probably due to winter injury, presumably caused by a severe cold spell during early spring. The injury was not confined to any one variety, but all trees examined showed the same conditions. If the central flower was missing, the lateral flowers on the spur had longer stems than normal.

Counts of the number of seeds in the fruits indicated that the number was higher in 1916 than in 1915. This may have been due partly to the somewhat better weather during blooming time in 1916 than in 1915. The data in table 49 suggest that the position of the fruit on the spur may afford another explanation for this observation. It is seen from these

TABLE 49. NUMBER OF SEEDS IN SHORT-STEMMED AND IN LONG-STEMMED FRUIT

Variety	Relative length of stem	Number of fruits	Average number of seeds	Percentage with less than five seeds
Tompkins King	Short	50	5.58	32
	Long	50	6.20	8
Baldwin	Short	50	5.38	32
	Long	50	6.04	14

figures that the short-stemmed fruits, which are developed from the central flower on the spurs, can set with fewer seeds than are needed for long-stemmed fruits which are developed from lateral flowers.

Seed content and weights of long-stemmed and of short-stemmed fruits produced on the same spur

Casual observations indicated that frequently the weights of fruits borne on the same spur were not in proportion to their seed content; in many cases the fruits were of the same size altho the seed number varied, and in not a few cases the fruits with the smaller number of seeds were larger than the fruits with the greater number of seeds. Further study showed that the fruits which attained the larger size with the fewer seeds were the short-stemmed fruits. Representative data are given in table 50:

TABLE 50. SEED CONTENT AND WEIGHTS OF LONG-STEMMED AND OF SHORT-STEMMED FRUITS BORNE ON THE SAME SPUR

Spur	Long-stemmed fruits			Short-stemmed fruits		
	Length of stem (millimeters)	Number of seeds	Weight of fruit (grams)	Length of stem (millimeters)	Number of seeds	Weight of fruit (grams)
1	24	8	27.0	16	4	29
2	25	6	11.0	18	6	14
3	21	5	20.0	21	6	22
4	19	7	19.5	10	4	25
5	24	6	21.5	14	4	24
Average	22.6	6.4	19.8	15.8	4.8	22.8

As has been mentioned, the short-stemmed fruit develops from the central flower, which is the first to open in spring. These flowers would probably be pollinated before the others, and it is possible that priority of pollination may be an advantage in causing a set with fewer seeds.

The short stems frequently become clubbed, or fleshy (fig. 8). The central fruits are obviously in the most desirable position from the standpoint of sap supply. The fact that short-stemmed fruits can attain a larger size with fewer seeds than long-stemmed fruits on the same spur, lends further support to the theory that abundant sap flow is essential for fruit setting. Seeds are of value since they stimulate sap flow, but the size of the conducting tissue leading to the fruit is of considerable importance as well. This fact also emphasizes the importance of having fruits borne under exactly the same conditions when studying the relations between weight of fruit, vigor of spur, and number of seeds. Only fruits that have developed from flowers having a similar position on their respective spurs can be compared.

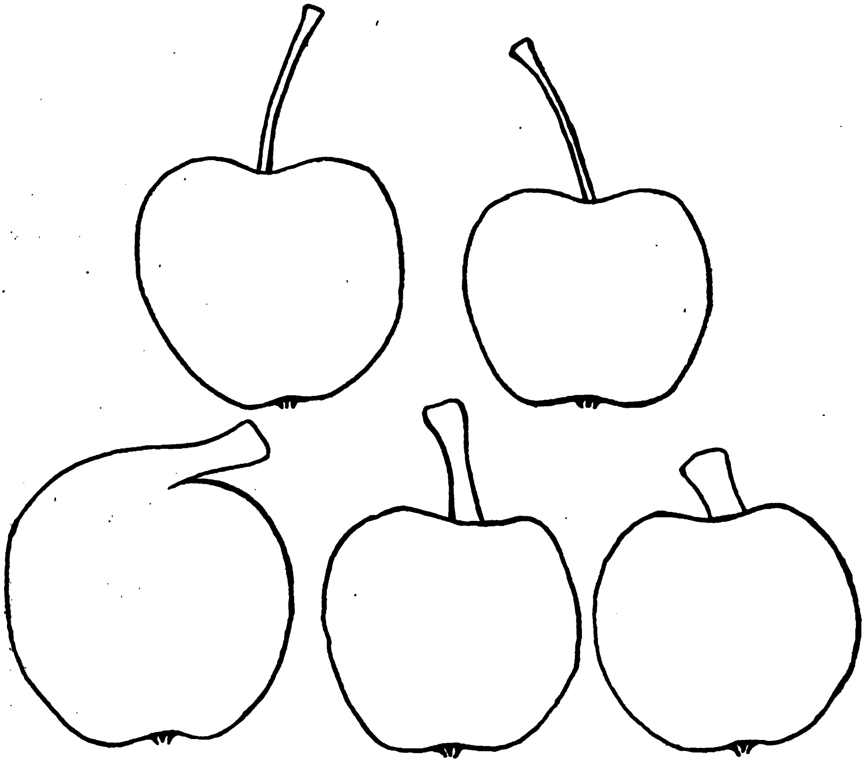

FIG. 8. FRUITS WITH LONG AND WITH SHORT STEMS
If a fruit with a long stem and one with a short stem are borne on the same spur, the former will usually be smaller than the latter even tho the former contains the greater number of seeds

Relation between number of seeds and size of fruits on spurs bearing one and on those bearing two fruits

In order to have fruits that are borne under the same conditions, only spurs bearing one fruit can be considered. If two fruits are borne on the same spur, the apples are developing under a handicap as compared with fruits borne singly. Data indicating that such conditions obtain are presented in table 51. Only the largest fruits on the two-fruited spurs were considered. The fruits were developed from lateral flowers on the spur. The variety was Tompkins King. It is seen from the table that

TABLE 51. WEIGHT OF SPUR, NUMBER OF SEEDS, AND WEIGHT OF FRUIT, ON ONE-FRUITED AND ON TWO-FRUITED SPURS

Number of fruits to the spur	Number of spurs	Average weight of spurs (grams)	Average number of seeds	Average weight of fruit (grams)
1	50	2.04	5.64	8.50
2	50	2.43	6.86	8.81

the spurs bearing one fruit produce apples nearly as heavy as the more vigorous spurs with two fruits, even tho the latter have more seeds.

Relation between aphid work and fruit development

Number of seeds in normal apples and in apples stung by aphids.—Another influence causing unequal conditions among fruits otherwise similar is that exerted by the sting of the aphid. Apples severely injured by aphids are easily recognized by their malformed condition (Parrott, Hodgkiss, and Lathrop, 1916). Such fruits will not drop even tho few or no seeds have been formed. Data regarding this point are given in table 52:

TABLE 52. AVERAGE NUMBER OF SEEDS IN NORMAL APPLES AND IN APPLES STUNG BY APHIDS

Condition of fruit	Number of fruits	Average number of seeds	Percentage having less than four seeds	Percentage having no seeds
Normal	50	6.94	22	0
Stung by aphids	100	2.93	87	20

In many cases the injury caused by aphids is not very noticeable, especially after the fruit has attained a diameter of several centimeters. There is no conspicuous malformation of the apple, and the spurs are apparently free from the pest. On close examination, however, many fruits apparently normal show the effects of aphid work. Such fruits are frequently found on weak spurs in spite of a low seed value. The stimulation resulting from the attacks of the aphid may be held accountable for such apparent discrepancies.

Water-core as affected by aphid work and water supply.—An observation regarding another influence of aphid work may be recorded at this time, since it shows that the aphid actually does influence the physiological activities of the fruit. In the early summer of 1916, water-core was noticeable on a number of apples, especially Fall Pippin and Tompkins King. All the water-cored apples from several trees were closely examined, and in every case observed such fruits had been stung by aphids. Not all the fruits injured by the lice were water-cored, but water-cored apples that had not been stung could not be found at that time.

That water-core may, however, result from other conditions besides aphid work is shown by the following observations: During the early summer of 1915, when the fruits were about three centimeters in diameter, a number of slender branches heavily laden with apples and leaves were cut from a tree and taken to the laboratory. The cut ends of the branches were placed in beakers containing water. Many of the fruits were removed, weighed, and cut open that same evening; none of these were water-logged. The next day all the apples from several different branches showed a water-cored condition. On the following day some fruits were again examined, all of which were found to be normal. Similar observations were subsequently made on twigs brought into the laboratory primarily for this purpose.

These facts can be accounted for by the following probable explanation: The ends of the freshly cut twigs permitted the free passage of water into the branch. Transpiration during the night was reduced to a minimum, which resulted in the accumulation of water in the fruit, thereby producing the water-logged condition. After some time the ends of the twigs became clogged, due to bacterial development, and as a result water entered less freely. The leaves transpired water more rapidly than it could be supplied thru the cut end of the twigs. This produced conditions favoring incipient drying, and hence the leaves began to withdraw water from the fruit. After the withdrawal of water had been going on for a time, the fruit regained its normal condition.

The water-cored condition observed in connection with aphid work cannot be changed by detaching the spur and allowing the leaves to withdraw the water. The leaves on detached spurs with aphid-stung fruit that was water-cored, dried up in all cases, while the fruit itself remained firm. Do apples injured by lice develop a greater sap concentration than they normally possess? Unfortunately no determinations were made regarding this question.

EXPERIMENTS CONCERNING THE ABSCISS-LAYER

The shedding of flowers and immature fruits is brought about by the formation of an absciss-layer similar to that which precedes leaf fall

(Pfeffer, 1904). The formation of such a layer was induced by the following means: (1) removing the fruit and leaving varying lengths of stem; (2) coating the fruit with vaseline; and (3) submitting the fruit to humid atmospheric conditions. The effects of these various treatments are given below.

The observations recorded suggest that the formation of the absciss-layer is associated with the inhibition of sap movement. So long as the sap passes into the fruit, as it does under normal conditions, or away from it as is the case when the leaves draw the watery sap from the fruit, the layer is not formed; but when the movement of sap ceases while the spur is still active, as it does when the fruit is removed from the stem or when transpiration is checked by coating the fruit with vaseline or by exposing the fruit and the spur to humid conditions, the absciss-layer is produced which brings about the shedding of the fruit or the stem.

Effect of removing fruit and leaving varying lengths of stem

A number of Maiden Blush fruits ranging from one to one and one-half centimeters in diameter were cut from the stems in such a way that the stem in each case remained attached to the spur. The length of the stems remaining after the removal of the fruits varied. In some cases the fruit was removed and the entire stem was allowed to remain on the spur; in other cases the stem was shortened to half its original length. The first experiment was performed on June 8, 1915. Six days later the short stems readily snapped from the spurs when touched and the long stems adhered somewhat firmly, while stems that had fruits did not come off when touched. Two days later the long stems from which the fruits had been removed fell naturally. Repeated experiments gave similar results. Removal of the fruit from the stem induced the formation of the absciss-layer which resulted in the shedding of the stem. The shorter the stem, the more quickly, apparently, was this layer formed.

Effect of coating fruit with vaseline

In connection with studies concerning aphid work, the entire fruit, stem and all, was coated with vaseline. All fruits so treated fell within a week, while uncoated apples remained attached. Subsequent experiments regarding the influence of coating the fruit with vaseline gave similar results. The same effect was obtained by coating the fruit with grafting wax. The treated apples were apparently normal in all respects. The effects of coating would be to inhibit transpiration and exchange of gases.

Effect of slow and of rapid drying of leaves on detached spurs with uncoated fruit and on detached spurs with vaseline-coated fruit.—Spurs with leaves and fruits were taken from the orchard and put in the laboratory. About half of the fruits were coated with vaseline, while the others were left untreated. Some spurs with the fruits coated and some with uncoated fruits were exposed in the laboratory with the cut ends in water; others of each lot were exposed in the same place but without having access to water.

After eight days the leaves on the spurs with their cut ends in water were green and turgid. The vaseline-coated fruits had all fallen from these spurs, while the uncoated fruits remained attached. In both cases the fruits were fully turgid. The leaves on spurs not having access to water were dried up and the fruits were shriveled, but both the vaseline-coated and the normal fruits remained attached.

Effect of a saturated and of a dry atmosphere on abscission of fruit on detached spurs

A number of spurs with leaves and fruits were brought into the laboratory and placed in a heavy paper sack, after which they were thoroly moistened by immersing them in water and then allowing the water to drain off thru perforations in the bag. They were given the same treatment every day for a week. Another lot of spurs was obtained at the same time, but they were accidentally overlooked when the others were moistened. At the end of the week, the spurs in the bag that had been moistened every day had lost all their fruit; the leaves were turgid and green, and remained attached to the spurs. The spurs that had not been moistened had lost all their leaves, which were yellow and crisp, but the fruit remained attached to the spur. The fruits in the humid atmosphere of the moistened bag remained firm, while those in the dry bag had shriveled. Similar observations were subsequently made.

SUMMARY

The facts and observations contained in the foregoing pages may be summarized as follows:

1. From two-fifths to four-fifths of the total number of flowers are lost during the early drop.

2. In some varieties practically all flower-bearing spurs set fruit after the first drop; in others almost half of the spurs fail to develop fruits.

3. The proportion of spurs that set fruit after the first drop varies considerably on different trees of the same variety and on different limbs of the same tree.

4. Only three to seven per cent of the total number of flowers finally develop into fruits.

5. If comparatively few flowers begin to develop fruits, the June drop will be small; if a large number of flowers begin development, the June drop will be heavy.

6. From one-sixth to one-third of the flower-bearing spurs finally set fruit.

7. The proportion of spurs that hold fruit after the June drop varies in different trees of the same variety and on different limbs of the same tree. These variations are not due entirely to the location of the limb or to the angle at which it grows.

8. A larger proportion of spurs set fruit on limbs that have produced a relatively light bloom than on limbs that have produced a full bloom.

9. Spurs on limbs with large leaves are more likely to set fruit than spurs on limbs with small leaves.

10. During 1915 there was no consistent difference in fruitfulness between the spurs arising from 1913 wood and those arising from older wood. Comparatively few spurs arising from lateral buds on 1914 wood set fruit in 1915. The shorter the terminal growth during 1914, the greater was the tendency for lateral buds to set fruit in 1915.

11. The spurs occurring near the end of a season's growth, or just before a zone of weak buds, are the most likely to set fruit. As a rule, the spurs in the terminal half of a given season's growth set more abundantly than spurs in the basal part.

12. Spurs that lose all flowers and fruits during the first drop average fewer flowers to the spur than those that hold fruit after the June drop.

13. Spurs producing many flowers are more likely to set fruit than those that produce a small number of flowers.

14. A higher proportion of the flowers produced on spurs with many flowers set fruit, than is the case with spurs producing few flowers.

15. Spurs making more than one centimeter of growth during the preceding season have a greater tendency to set fruit than those that make less than one centimeter of growth.

16. Spurs that finally set fruit are heavier than those that lose all their flowers and fruits. Those that hold fruit until the June drop are heavier than those that lose their flowers during the first drop.

17. Spurs bearing two fruits weigh more than those bearing only one fruit.

18. A larger proportion of strong spurs set two fruits to the spur than is the case with weak spurs.

19. Spurs which produce many flowers are heavier than spurs which are taken from the same limb but which produce few flowers.

20. Spurs arising from buds that are terminal on a spur growth of more than one centimeter have a greater average weight than spurs from buds borne at the end of a shorter growth.

21. The cylinders of conducting tissue have a greater diameter in the heavy spurs than in the light spurs.

22. The average weight of spurs on limbs that produce few flower-bearing spurs is greater than for spurs produced on limbs with a full bloom. Spurs with a given diameter on the former limbs weigh more than spurs with the same diameter from the limbs with a full bloom.

23. The water supply is a factor in increasing the size of leaves. More water passes to vigorous buds than to weak buds.

24. Frequently the spurs that set fruit make a vigorous lateral growth. Limbs that set fruit on a high proportion of spurs often produce the largest amount of lateral growth from flower-bearing spurs.

25. Limbs receiving a diminished supply of sap produce fewer fruits to a hundred spurs than limbs receiving a normal or an excessive supply of sap. The small spurs as well as the large ones are benefited by an increased amount of sap.

26. Vigorous spurs from which all the leaves are removed before the flower buds open are not so fruitful as similar spurs that are not defoliated. Vigorous spurs that have all but two leaves removed, set approximately as well as normal spurs, which usually have from seven to ten bud leaves. The proportion of spurs setting more than one fruit is three times as great in the case of the check spurs as in the defoliated lot.

27. Spurs inclosed in white translucent sacks are more fruitful than those inclosed in brown opaque sacks.

28. The apples that fall in the early stages of their development have fewer seeds, on the average, than the apples that remain on the tree; but many fruits remaining on the tree have few seeds, and many fruits that drop have a high seed content.

29. In general, the weight of the fruit is proportional to the number of seeds in the fruit. The vigor of the spur on which the fruit is borne, and the size of the embryos in the seeds contained in the apple, also play a part in determining the weight of the fruit. The term *seed value* emphasizes the quality of the seeds. This quality is manifested by the ability of the individual seeds to increase the weight of the fruit, and it is associated with the size of the embryo contained in the seed. The quality may be the result of cross-fertilization.

30. Spurs bearing fruit with a low seed value are heavier on the average than spurs produced on the same limb but bearing fruits with a high seed value.

31. Leaves on detached spurs that bear fruit remain turgid for some time, since they can draw water from the fruit. Apples with many seeds lose less water than those with few seeds.

32. Sap from fruit with few seeds depresses the freezing point less than does sap from many-seeded fruits.

33. Unsymmetrical fruits resulting from imperfect fertilization are more frequent in fruit that has dropped than in fruit that remains on the tree.

34. Short-stemmed fruits, which are developed from central flowers, have fewer seeds on the average than do long-stemmed fruits.

35. Fruits with short stems usually attain a greater weight than fruits with long stems borne on the same spur, even tho the latter may contain more seeds.

36. Fruits borne singly on vigorous spurs may attain a weight as great as that of the larger apples from spurs bearing two fruits, even tho the latter may have a greater seed content.

37. The average number of seeds in a normal apple is greater than in fruit that has been stung by aphids. Apples attacked by aphids remain attached to the tree even tho no seeds are formed.

38. Fruits stung by aphids may develop a water-cored condition. Such a condition is also caused by over-abundant water supply.

39. Removal of the fruit from its stem induces the formation of an absciss-layer between the stem and the spur, which results in the shedding of the stem. The shorter the stem, the more quickly is the absciss-layer formed.

40. Fruits coated with vaseline or grafting wax fall after one week.

41. Detached fruiting spurs kept in a receptacle with a saturated atmosphere lose their apples after several days; similar spurs kept in a dry atmosphere retain their fruit.

42. Vaseline-coated fruits on spurs with their stems standing in water fall after eight days; fruits similarly treated on spurs not having access to water remain attached to the spurs. Untreated fruits on spurs standing in water also remain hanging.

GENERAL DISCUSSION

The results presented in the foregoing pages emphasize the importance of vigor, more especially the vigor of the individual spur, as a factor in fruit setting. As compared to weak spurs, the previous season's growth of vigorous spurs is longer, the new spur growth is heavier, the leaves are larger and more numerous, there are more flowers to the spur, the diameter of the conducting tissue is greater, and the weight of the lateral spur growth is greater.

The vigorous spurs seem to favor fruit setting because they can supply the developing fruits with an abundance of water and food. Seeds appear to be valuable because they supplement the forces that bring sap to the fruit. Strong seeds are of primary importance for the setting of fruit on relatively weak spurs; they are of lesser importance for the setting of fruit on strong spurs.

The number of strong seeds is dependent on effective fertilization, which in turn presupposes cross-pollination. Even tho the grower may plant several varieties of the same fruit which bloom during the same time, nevertheless cross-pollination is frequently prevented by unfavorable weather during blooming time. Man has little control over the weather. On the other hand, man may influence the vigor of the tree by cultural methods. Trees in sod, for example, are usually less vigorous than trees in a tilled orchard. The latter, as a rule, produce heavier crops of fruit.

In Mr. Cornwall's orchard, at Pultneyville, New York, the Baldwin trees were heavily laden with fruit in 1915. Other Baldwin trees around Pultneyville produced relatively light crops that year. The weather at blooming time in that locality was cold, cloudy, windy, and rainy — very unfavorable for cross-pollination. The trees on the Cornwall farm were in the best of condition. The owner plowed his orchard very early in the spring and put in a cover crop the latter part of June and early in July. This treatment would be conducive to rapid, vigorous growth of the spurs early in spring, and early planting of the cover crop would tend to check further elongation and permit of abundant food storage in and near the terminal buds. According to the observations recorded herein, such conditions would favor fruit setting without the aid of many strong seeds, and hence a fairly good crop might be expected even tho the weather during blooming time were unfavorable. Plowing in late fall under some conditions may prove more advantageous than very late spring plowing, so far as setting of fruit is concerned.

The application of a quick-acting nitrogenous fertilizer, such as sodium nitrate, early in spring may have a decided effect in stimulating early and rapid spur growth that would be likely to set fruit the following year. Some evidence for this suggestion is contained in the paper by Lewis and Allen (1915), received by the writer while the present report was in the course of preparation.

Much has been said regarding so-called self-sterility of certain varieties which under a given set of conditions seem to be benefited by cross-pollination. As has been observed by Waite (1894) and others, the degree of self-sterility varies from year to year and in different trees of the same variety under different cultural treatments and in different localities. From the standpoint of the species, a condition of self-sterility is desirable because only cross-pollinated flowers would mature fruits and seeds on such trees. Cross-pollinated seeds would tend to produce more variable seedlings, and it might be expected that desirable variations, from the species' standpoint, would occur.

From man's standpoint, however, self-fertile varieties, or those that can mature fruit without strong seeds, are more desirable because there are more chances of a crop if the necessity of cross-pollination can be eliminated. So far as is known in the case of the apple, the presence of seeds has no effect on the quality of the fruit. Seeds affect the size, but size can be produced without the aid of seeds. It is conceivable that a tree bearing a heavy crop of many-seeded fruits is being devitalized to a far greater extent than another tree of the same variety bearing a crop of fruits equally heavy but having relatively few seeds. This hypothesis presupposes that the production of seeds requires more energy and food than the mere production of the flesh of the fruit.

The problem, then, it seems, is to find cultural treatments that are favorable to self-fertility. This is by no means a simple problem. One should not expect, for example, that the soil treatment which proves favorable for one or more varieties will prove favorable for all. Any treatments, however, that produce relatively long spur growth and provide for an abundance of stored food, and any treatments that influence the vigor of the individual spur, may be expected to be favorable for the development of blossoms into fruit without cross-pollination. Unfavorable climatic conditions may be involved in the self-sterility of a given variety; if such is the case, nothing can be done but to make the best provisions for cross-pollination.

The observations and experiments recorded in the preceding pages justify the tentative conclusion that unfavorable conditions of nutrition and water supply are among the basic factors which cause the normal drop of flowers and partially developed fruits of the apple. All factors that have a direct or an indirect influence on nutrition and water supply of the flower and the fruit, such as pollination, weather, cultivation, and the like, are of importance. Fruit development, however, is possible without cross-pollination and even under relatively unfavorable weather conditions, so long as the young fruit has an abundant supply of water and of readily available food.

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THE DECOMPOSITION OF SWEET CLOVER (MELILOTUS ALBA DESR.) AS A GREEN MANURE UNDER GREENHOUSE CONDITIONS

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THE ANTHRACNOSE DISEASE OF THE RASPBERRY AND RELATED PLANTS[1]

WALTER H. BURKHOLDER

The raspberry is one of the oldest of the small fruits. It belongs to the genus Rubus, of the family Rosaceae,[2] and comprises a number of varieties which with a few exceptions originated from three main sources — the European red raspberry (*Rubus idaeus* L.), and the two American species, the red raspberry (*Rubus idaeus* var. *aculeatissimus* [Mey.] Regel & Tiling) and the black raspberry (*Rubus occidentalis* L.). The first of these three species was under cultivation as early as the fourth century, but the domestication of the other two is of very recent date.

Most of the commercial varieties of the raspberry in North America originated from the two indigenous species, the European red raspberry not being sufficiently hardy and vigorous to withstand the climatic conditions of this country. Two hybrids also are grown extensively here. They are the purple-cane raspberry, formerly known as *Rubus neglectus* Peck but now claimed by Anthony[3] to be a cross between the red and the black raspberry; and the loganberry, considered to be a hybrid between the European red raspberry and the western dewberry (*Rubus vitifolius* Cham. & Schlecht.).

In the United States these berries are grown throughout the northern part of the country and in the cooler hilly regions. According to the Thirteenth Census Report, New York State in 1910 ranked first in the production of this fruit, with 11,057 acres, and Michigan second, with 8786 acres; no other State had as much as 4000 acres. In New York the raspberry industry is limited to small districts throughout the western part of the State, with the exception of an area in the Hudson River Valley. In these localities during the past ten years or more there has been a marked decrease both in acreage and in yield, which is attributed to the general prevalence of diseases to which the host is susceptible.

The anthracnose disease, yellows, cane blight, and crown gall are the commonest diseases affecting the raspberry. Anthracnose occurs in practically every locality and is considered the most serious disease of

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[1] Also presented to the Faculty of the Graduate School of Cornell University, June, 1917, as a thesis in partial fulfillment of the requirements for the degree of doctor of philosophy.

AUTHOR'S ACKNOWLEDGMENTS. The writer wishes to express his indebtedness to Professor Donald Reddick, under whose direction the work was performed, and to Professor V. B. Stewart for help and criticism in preparation of the manuscript.

[2] Card, Fred W. The brambles. *In* Bush-fruits, p. 43–336. 1914.

[3] Anthony, R. D. Some notes on the breeding of raspberries. New York (Geneva) Agr. Exp. Sta. Bul. 417:75–88. 1916.

the plant. It is known also as *cane rust*, *spot*, *scab*, or *sun-scald*. It occurs on all the above-named species of Rubus and their hybrids, and in addition is found on various other species of this genus, such as the blackberry (*Rubus* sp.), the eastern and the western dewberry (*Rubus villosus* Ait. and *Rubus vitifolius* Cham. & Schlecht.), the cloudberry (*Rubus chamaemorus* L.), and the European bramble (*Rubus fruticosus* L.). Halsted (1894)[4] has suggested that the anthracnose of the rose may be identical with that of the raspberry, but this has not been proved.

Of the species of Rubus affected by anthracnose, the black raspberry (*Rubus occidentalis*) exhibits the greatest susceptibility to the disease. On this species the disease is very severe, not only on the cultivated varieties but also on the wild forms. Observations show, moreover, that the hybrid generally known as *Rubus neglectus* has inherited this susceptibility, and anthracnose occurs commonly in plantations where this hybrid is grown. On the other hand, the commercial varieties of the red raspberry, which arise mainly from *Rubus idaeus* var. *aculeatissimus*, show a marked resistance to the disease. Very few fields planted with these varieties have been observed where the anthracnose was considered to be of any economic importance. Furthermore, it is noticeable that on the wild forms of this species the disease seldom occurs except on the leaves, where it is never serious. In New York State the blackberry is rarely subject to anthracnose, but according to Lawrence (1910) and Jackson (1913) it is very susceptible to the disease in the northwestern United States. Anthracnose is more or less injurious also to the dewberry and the loganberry.

Varietal susceptibility is not markedly perceptible within the above-named species. Taylor[5] reports a desirable black raspberry, the Hoosier, which is considered to be resistant; at least it has remained free from the anthracnose disease up to the present time. Among the varieties of the red raspberry the Cuthbert is held to be the most resistant, though all the varieties of this species exhibit but very little susceptibility. The Columbian, a purple-cane variety, formerly was regarded as nearly immune, but it now exhibits a marked susceptibility. It is not known whether this variety really possessed resistance at one time or whether the stock was merely free from the disease. At present very few growers recognize any difference in susceptibility between the black raspberry and the purple-cane varieties. Lawrence (1910) states that among the varieties of blackberry the disease is severe on the Snyder and the Kittatany, while on the Himalaya Giant it occurs only on the leaves.

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[4] Dates in parenthesis refer to bibliography, page 182.

[5] Taylor, William A. Hoosier raspberry. *In* Promising new fruits. U. S. Dept. Agr. Yearbook 1910: 429–430. 1911.

HISTORY AND GEOGRAPHICAL DISTRIBUTION OF THE DISEASE

The anthracnose disease is possibly of as widespread distribution as the raspberry itself. Massee (1907) states that it occurs in Europe, America, and Australia but has been found more commonly on the last two continents. The disease was first reported in Italy, by Spegazzini (1879), on the leaves of the cloudberry (*Rubus chamaemorus*). The following year it was brought to the attention of Burrill (1882) in America, where in certain localities it was causing serious losses to the black raspberry crop.

It is thus difficult to determine whether anthracnose is of American or European origin. The disease has been more destructive in America, doubtless due to the fact that the most susceptible species of the genus Rubus are under cultivation here. Cooke (1906) even expresses doubt that the disease is to be found in England, and Sorauer (1908) does not mention its occurrence in Germany. On the other hand, the disease spread rapidly in America, and ten years after it was first noticed, in Italy, Scribner (1888) reports it as being widespread and destructive in the United States. Dearness collected diseased material in Canada in 1891 and contributed it to the exsiccati of Seymour and Earle's *Economic Fungi*. A few years later McAlpine (1897) reported it from Australia.

ECONOMIC IMPORTANCE

It is difficult to estimate the losses caused by anthracnose, since the disease varies greatly with climatic conditions and the host plant is often subject to less striking diseases which are nevertheless of considerable importance. Such diseases as yellows and crown gall are frequently overlooked and their injury to the plant attributed to anthracnose when that is present. No doubt the estimates of losses due to anthracnose have been in some cases too high, although it is one of the most serious diseases of the raspberry. For these reasons, and from the fact that the disease affects the plant only indirectly, little data are available showing the percentage of loss caused by anthracnose. A few investigators, however, have made estimates which may be mentioned here.

Burrill (1882) cites an instance of a raspberry plantation ordinarily yielding a profit of $400 per year, which profit was reduced to such an extent by one attack of anthracnose that expenses were scarcely met. Scribner (1888) estimates the losses in southern Missouri on the blackcap raspberry as being from ten to twelve per cent of the entire crop. The disease is reported by Orton and Ames (1908) to have injured sixty-three per cent of the raspberry crop in Nebraska, fifty per cent in Wisconsin, and even a greater percentage in Illinois. Lawrence (1910) cites instances in which the percentage of infected blackberries at certain pickings was as high as fifty.

Even more striking is the fact that in certain localities in New York State the growers have been obliged to discontinue the raising of berries. They attribute the cause of the failure of the crop to the anthracnose disease. In a report of a survey of small fruits in western New York, Buchholz (1911) states that by a conservative estimate seventy-five per cent of the black raspberry patches were diseased with anthracnose. He states also that the average yield of the raspberry, at one time, was two thousand quarts per acre in this section, while now even in favorable years it is difficult to obtain this quantity. Furthermore a plantation formerly yielded a crop annually for a period of from six to seven seasons, while in recent years only about four crops are harvested from a plantation. That a correlation exists between the general prevalence of the anthracnose disease and the reduction in yield of the crop in late years is evident.

SYMPTOMS

The anthracnose disease appears on the canes, the petioles, the pedicels, and the leaves of the raspberry. Lawrence (1910) reports that in Washington it occurs commonly on the fruit of the blackberry and rarely on the fruit of the loganberry. The writer has not observed these fruits to be affected in New York State.

ON THE CANES

The presence of the disease is first noticed in the spring when the young shoots are about six inches high. Small reddish purple spots, which are slightly raised, are seen singly or in groups on the tender canes, first appearing a short distance from the growing tip. The spots enlarge slowly, and the centers become sunken and assume a pale buff color while the advancing margin is raised and purple. A single lesion is more or less oval in outline, the greater diameter lying along the shoot; but usually the spots anastomose and form irregular blotches which frequently encircle the cane (fig. 12, and fig. 13, A). In the center of each spot is a small pustule visible to the naked eye. Later in the season, with the further growth of the host, longitudinal cracks appear in the spots. During the winter these enlarge so that in the spring the second year's growth is often split to the pith (fig. 13, B).

A somewhat different type of lesion has been found on the shoots of the purple-cane and red varieties of the raspberry. It differs from the spot described above in that a knotty growth develops, which occasionally becomes twice the diameter of the normal cane. These knots arise from lesions formed when the tissue is very young and tender, and in some cases cause a distortion of the cane. This type of injury, which has never

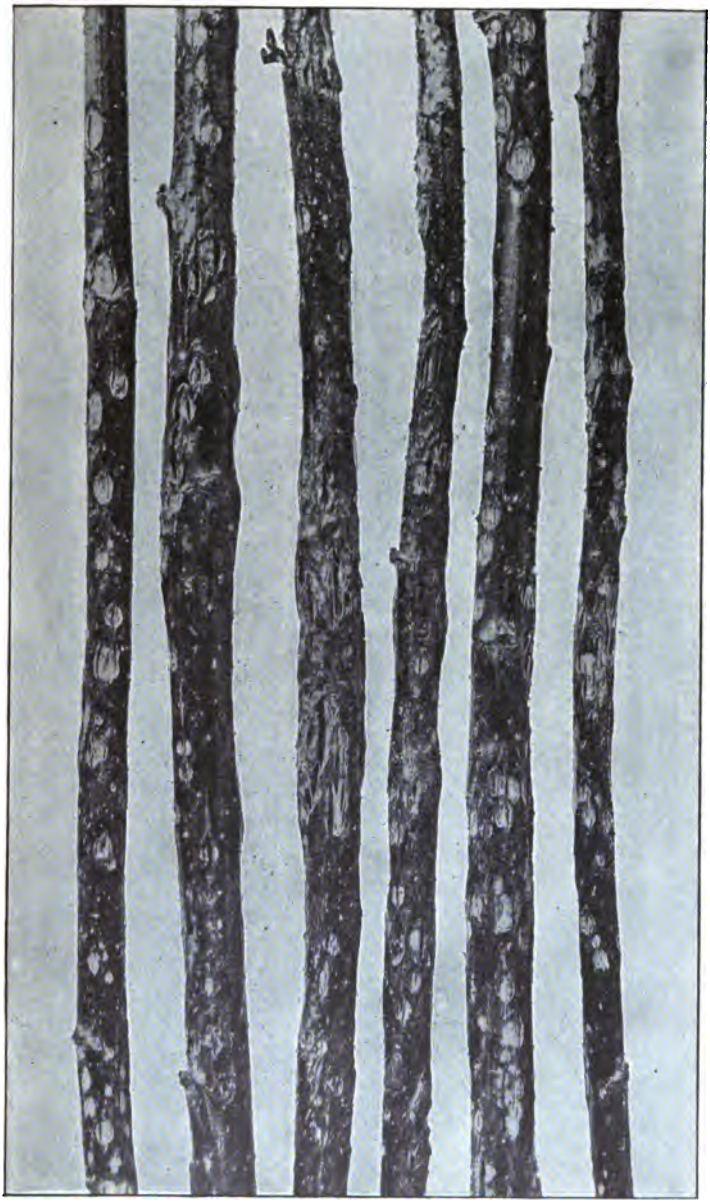

FIG. 12. ANTHRACNOSE LESIONS ON THE CANES OF RED RASPBERRY
A severe infection, showing various stages in the development of the lesions

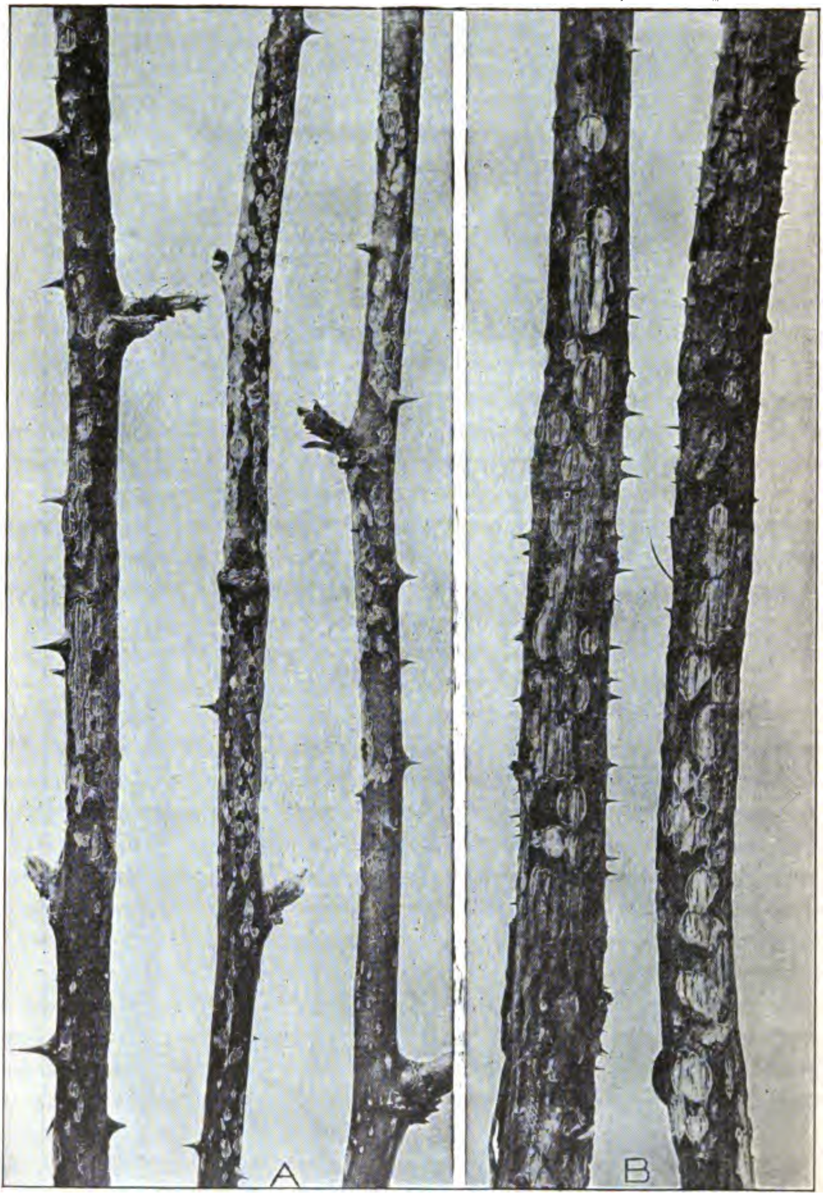

FIG. 13. ANTHRACNOSE ON SPECIES OF RUBUS

A, Lesions on the canes of blackberry; B, lesions on the canes of black raspberry, showing the typical fissures been observed on the black raspberry, was first noticed by Stewart, Rolfs, and Hall (1900).

As a rule the lateral branches are less severely affected than the principal canes. Occasionally young laterals are killed when they first develop. These branches become dry and the tissue is hard and brittle, while scablike lesions entirely girdle the base and extend up the young shoot. The lateral shoots that arise from two-years-old canes and bear the fruit, however, are never seriously diseased. Although spots often occur on them the lesions are small and cause comparatively little injury.

ON PETIOLES AND PEDICELS

Anthracnose is not found commonly on the petioles and the pedicels of the raspberry. When it does occur there the spots are similar to those on the canes, although frequently the purple margins are absent and the affected area is pale buff, raised and scablike. The diseased petioles and pedicels become brittle, while the fruit is retarded in its maturation in proportion to the severity of the infection.

ON THE LEAVES

The disease appears on the leaves of the raspberry somewhat later in the season than on the canes. Small purple spots with light-colored centers may appear scattered irregularly over the upper surface of the leaf, or they may be found in rows where the leaf is creased or folded (fig. 14).

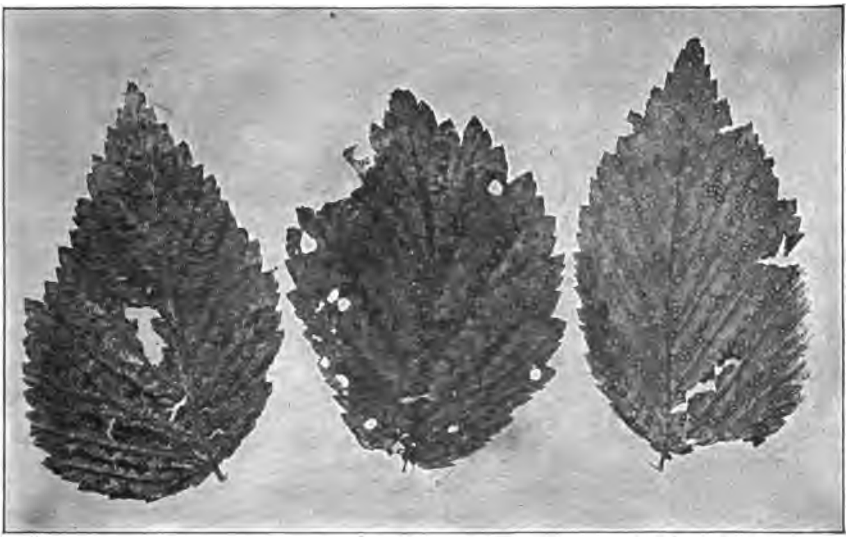

FIG. 14. ANTHRACNOSE DISEASE ON THE LEAVES OF RASPBERRY

The spots occur in rows, but not necessarily on the veins

Frequently in the latter case the spots anastomose. Since the lesions are very small, about one to two millimeters in diameter, the foliage is not injured to any extent by the anthracnose, although later in the season the affected leaves may become more or less ragged. It has been observed also that in some cases the spots drop out and give the shothole effect characteristic of many leaf spots.

The common leaf spot of the raspberry, which may be confused with anthracnose, is caused by a species of Septoria. The lesion differs from that of the anthracnose disease in being irregular in outline and pale brown in color, with minute pycnidia just visible to the eye. In the case of the Septoria disease a yellowing and dying of the leaves occurs.

ETIOLOGY

The anthracnose disease of the raspberry is caused by the fungous pathogene *Plectodiscella veneta* Burkholder.

MORPHOLOGY

The mycelium of *Plectodiscella veneta* when mature is hyaline and composed of minute cells many of which are globose. In all stages the fungus is very local and forms a stroma in the epidermal and subepidermal cells of the host. This stroma is frequently subcuticular, but never has it been

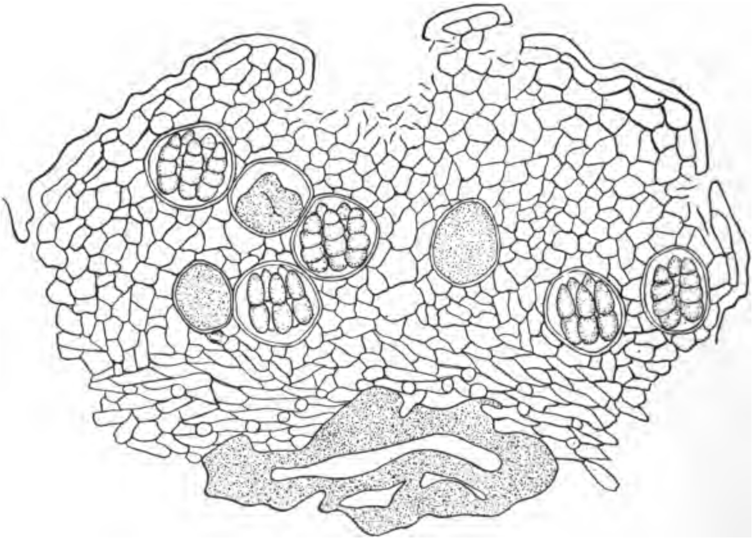

FIG. 15. ASCOCARP OF PLECTODISCELLA VENETA

Longitudinal section through the ascocarp, showing various stages in the development of the ascospores. Outlined with camera lucida from prepared slide. The tissue is somewhat shrunken. × 850 observed to be entirely subepidermal. The tissue of which it is composed is in its mature condition hyaline, and varies from a pseudoparenchyma in the outer area to a plectenchyma next to the host cells. In the leaves the stromatic tissue consists only of one to several layers of fungous cells. The imperfect stage arises from this stroma both on the leaves and on the canes, while the ascigerous stage has been observed to arise only from the stroma on the canes.

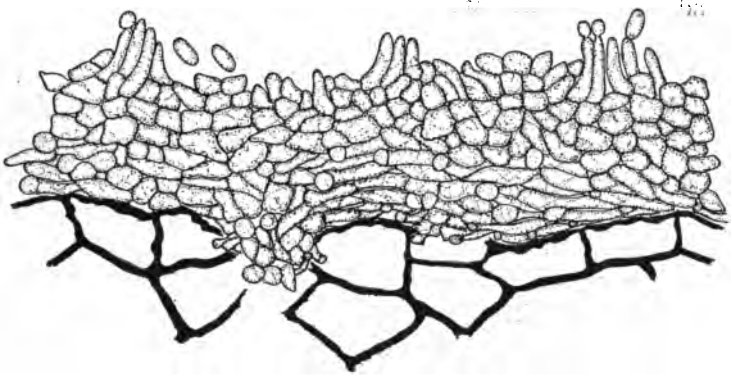

FIG. 16. ACERVULUS OF PLECTODISCELLA VENETA

Section showing the differentiation in the upper and the lower layer of the stroma, also the conidiophores arising in groups. Outlined with camera lucida from prepared slide. The tissue is somewhat shrunken. × 850

The ascocarps of *P. veneta* are pulvinate, from deep brown to black, and about 75 μ in diameter (fig. 15). They are borne singly or in groups, and they frequently anastomose and give rise to variously shaped bodies. The dark color is due to a layer of thick-walled, brown cells which cover each fruiting body. These cells at maturity split apart and expose the tissue within, which is hyaline, pseudoparenchymatous, and usually in a state of disintegration. The cells of the ascocarps are somewhat larger and thinner-walled than those of the stroma. Globose, thick-walled asci, from 24 to 30 μ in diameter, are scattered irregularly throughout the interior of the fruit body and either lie against one another or are separated by the fungous tissue. The ascospores are borne parallel to one another in the ascus. They measure from 18 to 21 μ in length and from 6.5 to 8 μ in width, and are hyaline, four-celled, ovate, and slightly curved, with constrictions at the septa. The basal cell is larger and more obtuse than the apical cell.

The imperfect stage of *P. veneta* has been known in literature as *Gloeosporium venetum* Speg. Short, unbranched conidiophores are produced, frequently in groups over the surface of the stroma, and these bear unicellular conidia which are held together in a mucilaginous substance (fig. 16).

The conidia are hyaline, and from oblong to elliptical and in some cases slightly dumbbell-shaped. They are characterized by having an oil globule at each end, and they measure from 5 to 7 μ in length by from 2.5 to 3 μ in width.

NOMENCLATURE

The conidial stage of the fungus was first collected by Spegazzini in 1877 in Italy on *Rubus chamaemorus*, and was named by him *Gloeosporium venetum*. In America the organism was first mentioned by Burrill (1882). He evidently either had not seen Spegazzini's description or considered the two fungi to be distinct, since he gives no name to the pathogene. Burrill states, moreover, that possibly the raspberry fungus belongs to the genus Gloeosporium, but he thinks the fact that the spores are not borne beneath the epidermis throws some doubt on its position. Ellis (Ellis and Everhart, 1887) described the fungus under the name *Gloeosporium necator* E. & E., although previously in a letter to Burrill he had referred it to the genus Ascochyta. The similarity of *G. necator* E. & E. to *G. venetum* Speg. was recognized by Ellis, but the two species were separated by him because the latter is foliicolous. From this it is evident that he had not observed the pathogene on the leaves of the raspberry. In the following year Scribner (1888) pointed out the fact that since *G. necator* E. & E. agrees in all characters with the fungus previously described by Spegazzini, and since it occurs on both the leaves and the canes, it should be known as *Gloeosporium venetum* Speg.

In 1914 the writer (1914) reported the discovery of an ascomycete which he regarded as the perfect stage of this fungus, and in a later paper (1917) he showed the connection between the two forms. The fungus was given the name *Plectodiscella veneta*. The only representative of the genus Plectodiscella known previous to 1917 was *P. Piri*, described by Woronichin (1914) as occurring on the leaves of apple and of pear. The morphology of the two species is strikingly similar and it is apparent that the ascigerous stage of *Gloeosporium venetum* belongs in the same genus. With the exception of the work of Von Höhnel (1909), but little careful investigation has been conducted on this group of ascomycetes, and the systematic position of the genus Plectodiscella is somewhat doubtful. Woronichin merely places it somewhere between the genus Elsinoe Rac. and the true discomycetes. When it is considered that the position of Elsinoe is also indefinite, the taxonomic position of the genus Plectodiscella becomes more difficult to determine. Both genera, however, show close relationship with the order Plectascales, and no doubt should be placed there.

LIFE HISTORY

The ascigerous stage

During the season of 1914 the fungus was kept under close observation in order to determine when the ascocarps begin their development. Repeated examinations of anthracnose lesions on young canes of the purple-cane raspberry, at Brant, New York, showed that the ascocarps begin to develop during the latter part of the summer. The sexual fruiting bodies were found more commonly on this hybrid. The perfect stage of the fungus has been collected by the writer also on the black raspberry and the red raspberry, while Rees (1915) has reported it on the blackberry.

About the middle of August, when the immature ascocarps are first observed, they appear as minute spots, from deep brown to black, scattered singly or in groups over the buff-colored and sunken part of the anthracnose lesion. These spots are barely visible to the eye, and only visible at all because of the contrast in color with the surrounding tissue. At the end of the winter the entire lesion assumes a dark brown hue, and it is with great difficulty that the fruiting bodies are then observed, even with a hand lens.

In the early stages of its development the ascocarp is merely a raised part of the stroma, the tissue of which is but slightly differentiated, and the asci have not started to develop. A layer of brown cells covers the fruiting body, forming a more or less circular structure which gives the appearance of a shield, less perfect, however, than those found in the family Microtheriaceae. The cells near the center of the shield are thinner-walled, and with the further growth of the tissue within they soon split apart in a stellate manner. By autumn the asci have appeared and are found as globose bodies filled with a homogeneous mass of protoplasm. In some instances the spores are formed by this time. The fungus may pass the winter in this condition.

In the autumn, or more often the following spring, the asci mature and the homogeneous mass of protoplasm gives place to eight four-celled ascospores. In the formation of these spores the middle septum is laid down much earlier than the other two, and so it is not uncommon to find two-celled spores. Later these two cells divide and the mature ascospore becomes four-celled. The constrictions formed at the septa during this second division are frequently not so great as at the first, or middle, septum. Occasionally one of the cells fails to divide and an ascospore of three cells is formed.

During the formation of the spores the disintegration of the fungous tissue about the asci takes place, and with the rupturing of the outer layer of the ascocarp the asci are exposed. Frequently the asci lying in this exposed condition, surrounded by the remainder of the ascocarp, give the appearance of one of the true discomycetes. This, however, is brought about by the persistency of the outer cells of the shield-like layer which covers the immature ascocarp. In the presence of sufficient moisture the exposed asci elongate to approximately three times their usual length. This process is very rapid and may be observed under a microscope when a fragment of tissue containing asci is placed in a drop of water. The lower part of the ascus remains fastened in the cavity in which it was borne, giving a conical shape to the body which raises itself above the surrounding tissue. The spores gather at the tip of the ascus and from there are ejected into the air. They have been caught at a distance of one centimeter above the lesions.

Even in a single ascocarp all the asci are never of the same age, and the ascocarps on the same cane seem to vary in this respect. In 1915 mature ascospores were first observed about the first of June, while other ascospores were not mature until later in the summer.

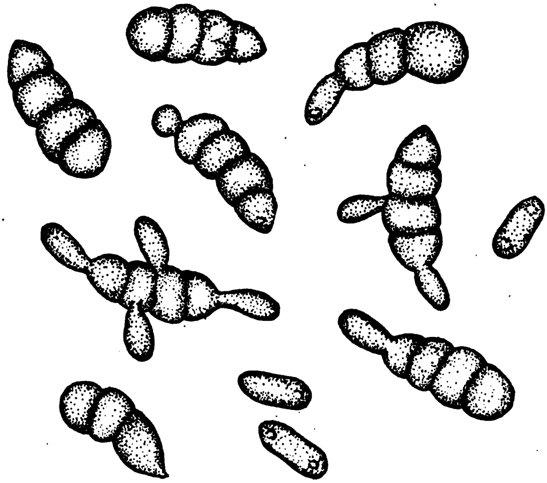

FIG. 17. ASCOSPORES OF PLECTODISCELLA VENETA
Showing various stages in the formation of the sprout conidia. × 1132

The ascospores, like the conidia, have walls which are very gelatinous and sticky, and great difficulty was experienced in trying to pick up single spores by means of a glass tube, as described by Barber.[6] The spores adhere especially to the glass slides, and it was impossible to get them into the bore of the tube. Single asci, however, could be separated in this manner.

When placed in tap, rain, or distilled water, or on nutrient agar, the mature ascospores germinate very readily. They swell somewhat, and within less than two hours a short sterigma is produced from one or each of the cells. A sprout conidium is formed, which is from oblong to elliptical in shape and is identical with the conidia of the fungus borne in the acervuli (fig. 17). When fully mature the sprout conidia drop from the sterigmata but they do not germinate immediately. After a short period of rest, from twelve to twenty-four hours, a germ tube is developed and mycelium is formed. When an ascus is placed in a drop of water or on agar, the spores within germinate by sending the sterigmata through the wall of the ascus and producing the sprout conidia on the outside. These in turn germinate. After the production of the secondary spores the ascospores shrivel and disintegrate.

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[6] Barber, Marshall A. On heredity in certain microorganisms. Kansas Univ. sci. bul. 4:3–48. 1907.

During the spring and early summer the ascospores are ejected from the asci. Falling on the young shoots, apparently the spores produce the sprout conidia which later send forth germ tubes that penetrate the host tissue. Because of their gelatinous walls, the ascospores could readily adhere to the smooth surface of the cane and germinate when sufficient moisture is present. These steps, however, have never been followed by the writer.

The imperfect stage

As stated above, *Plectodiscella veneta* may pass the winter in the ascigerous stage. The ascocarps, however, are very rare and the pathogene as a rule winters over as mycelium in the canes. With the usual periods of rainfall in the spring, accompanied by warm weather, a great many conidia are produced in the old lesions, and these conidia readily infect the young raspberry shoots which at this time are about eight to twelve inches high.

The germination of a conidium on a young raspberry cane has been observed only on canes in a moist chamber. Here the spore germinates by producing one or more germ tubes, which branch profusely and form a minute cushion of cells. The cushion adheres closely to the host and is not readily removed, evidently because of the hyphae which have begun to penetrate the cell or cells of the host beneath. It is difficult to determine whether the minute fungous mass is subcuticular or not. On the young shoots of the raspberry used (*Rubus neglectus*) the cuticle is poorly developed. Later, however, when the fungus has spread through the epidermal cells, the cuticle may be found to extend a short distance over the lesion. After the pathogene has entered the cells of the host, further growth continues in the formation of a stroma, the center of which appears as a small pustule visible to the eye. This raised part of the stroma has nothing whatever to do with the fructification of the fungus, as one is at first led to believe, but is merely the accumulation of fungous cells at the point of infection. While the tissue of the cane is tender the mycelium grows rapidly, but growth is soon checked upon the hardening of the host cells at maturity. Consequently a lesion resulting from a single infection seldom reaches a width of more than one centimeter. With the further tangential growth of the cane underneath the lesion, the stroma is often torn apart, and during the second year it is found primarily about the edges of the spot.

Shortly after the stroma begins to develop, conidiophores arise, usually in groups over the surface, and these bear conidia. The conidia are embedded in a gelatinous substance which is soluble in water, and therefore they may be splashed by rain to the surrounding canes. According to Appel (1915), this gelatinous substance which covers the spores also aids them in sticking to the heavy wax cuticle of the raspberry cane.

The conidia germinate within a period of from three to twelve hours in water and on various nutrient media, but the writer has never observed more than a forty-per-cent germination. From the few observations made their vitality appears to be short, although Scribner (1888) was able to germinate spores that had been kept in the herbarium for several months. Drying the conidia on a glass slide for twenty-four hours does not injure their vitality, but repeated drying causes their death.

It is possible that the fungus dies after the production of conidia in the spring, since the writer has found but few conidia in old lesions after early summer and these were evidently left from the early production. Furthermore, spores were never produced when diseased canes that had borne fruit were placed in moist chambers, and the writer has never been able to obtain cultures of the fungus from plantings of such tissue. The death of the pathogene cannot be attributed to the dying of the host after fruiting time, as the fungus on one-year-old canes which have winterkilled may produce conidia in great abundance the following spring. Here it should be remembered that, although raspberry roots are perennial, the canes are biennial. The fungus living on the latter has a similar life period, even though it is not entirely parasitic on its host.

PATHOLOGICAL HISTOLOGY

Very little has been done by previous investigators on the pathological histology of raspberry affected with anthracnose. Scribner (1888) states that " the greatest injury is confined to the cambium layer, or the portion through which the sap is conveyed in the process of growth." Paddock (1897) states that " it is not known that the fungus works into the wood but its attacks occasionally cause the canes to crack and expose the pith." As to the exact tissues invaded by the fungus and the various pathological conditions which arise in them, nothing has been written.

The following observations were made on diseased canes of the Columbian variety of raspberry. This is a purple-cane variety and possibly is more severely attacked by the fungus than are any of the blackcap varieties. The lesions frequently develop to a greater extent on the former than on the latter, and thus a wider range of stages may be observed.

Infection takes place more readily on young and tender canes, and throughout the summer the small reddish purple spots indicating recent infection are found only on the tips of the shoots. During the early development of the disease the epidermal and the outer cortical cells collapse. At this early stage the fungus has never been noticed in these cells, but since the hyphae are very slender and the dead host tissue becomes so deeply stained the mycelium would be difficult to detect. The parenchyma below this collapsed region is evidently affected with a toxin or enzyme either produced by the fungus or resulting from the death of the host tissue. The cells in this region divide very rapidly in a tangential plane. This hyperplasia of the parenchyma cells causes the young lesion to be slightly raised at first on the surface of the cane, but with further development of the pathogene this tissue collapses and the lesion becomes sunken. A thin stroma then fills the cavity and a very small trace of the cortex remains or frequently its destruction is complete. During this time the organism continues its invasion of the parenchymatous cells between the vascular bundles. A hyperplasia of the phloem next occurs, but no further pathological condition arises within this tissue in case of late infection. On the other hand, with early and severe infection the phloem cells collapse and the fungus destroys the cambium and extends to the xylem.

Normally a ring of fibers is formed in the cortex, which are not in a continuous sheet but appear in groups associated with the phloem. If the pathogene reaches these before they mature, the fibers become abnormal or are completely suppressed. After their development, however, they are very resistant to the attacks of the fungus.

The xylem tissue is the least affected by the anthracnose disease, but if infection takes place when the vascular bundles are small the xylem ceases its normal development. It is difficult to determine whether this tissue is invaded by the pathogene, since only the outer edge shows the necrotic condition which might be indicative of the presence of the fungus. Frequently it is impossible to determine the position of the cambium, as the diseased phloem and xylem lose their distinctive characteristics and become fused. Although hypoplasia is exhibited in the xylem beneath the infection, it is offset by an excessive development of that tissue on either side of the diseased spot. This is likewise true of the phloem.

Because of the increased development of the vascular bundles on either side of the lesion, and the hypoplasia and destruction of the tissue within the lesion, an uneven growth of the cane results. Longitudinal fissures appear in the diseased area and later extend into the xylem and in some cases into the pith. This splitting of the cane is caused by the strain placed on the diseased tissue due to the continued tangential and radial growth of the surrounding normal tissues. It is delayed, however, to some extent by the development of a group of parenchyma cells which take the place of the phloem and the inner cortex. In cross section this group of cells is wedge-shaped, with the apex extending toward the center of the cane, and in the outer edge small bundles of fibers frequently may be observed. This tissue collapses soon after development and is torn apart when the fissures occur in the lesion.

CULTURAL CHARACTERS

Miss Stoneman (1898) states that this fungus "does not adapt itself readily to artificial culture, and considerable difficulty was experienced before obtaining a pure culture." In making plantings of diseased tissue the writer found that the fungus develops so slowly that contaminations are likely to grow over it. The growth of the organism from such plantings cannot be detected microscopically for five or six days, and a week more is required for sufficient development before the fungus can be removed to a test tube. Spore dilution plates are as satisfactory a method of isolating the pathogene as any, and conidia are readily obtainable throughout the summer and even late in the autumn. A pure culture of the fungus may be obtained also by inverting a sterilized petri dish containing a thin layer of nutrient agar over a small piece of raspberry cane bearing ascocarps. When the piece of bark is moistened the ascospores are ejected from the asci and lodge on the agar surface above. The spores can then be located easily with a low-magnifying microscope. By marking the position of the spores on the lower side of the petri dish their germination and development can be observed. The ascospores first produce sprout conidia, but further development on the medium is identical with that from the conidia of the fungus.

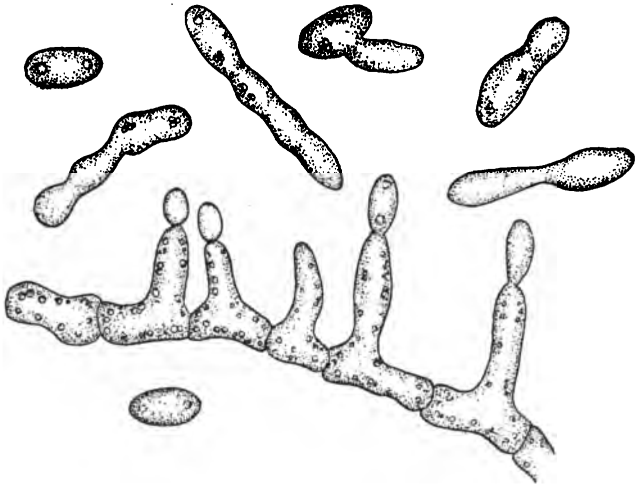

FIG. 18. CONIDIA OF PLECTODISCELLA VENETA
The conidia and conidiophores were produced in culture. Some of the conidia are germinating. X 1132

The growth of the fungus in culture is very peculiar. Miss Stoneman (1898) states that several isolations were made before she was satisfied that she had obtained the desired organism. The conidia germinate on various kinds of agar within a period of from three to twelve hours (fig. 18). From a single conidium one or more germ tubes are developed, which at first grow rapidly. Septa are formed, the cells become swollen, and soon the conidium is indistinguishable from the cells of the mycelium. In tap or rain water, growth ceases at this stage. No appressoria have been noticed. On potato or nutrient agar, the primary germ tubes branch, and their cells, which are globose, form a more or less compact mass. The colony is circular in outline and as the mycelium grows older the color changes to a pale vinaceous pink. Hyphae radiate in all directions from the fungous mass but only for an exceedingly short distance. On media containing a small amount of agar a more nutritive growth occurs, the hyphae of which are filamentous, with occasional globose cells.

The aerial growth of this fungus in culture is comparatively slow, and continues as a piling-up of cells forming a wrinkled mass having the appearance of sclerotia (fig. 19). In some cases this mass has a shining appearance, while in others fine aerial hyphae are formed over the compact growth. The color of the culture varies from light russet-vinaceous to maroon, while the edges of the colonies are lighter in color due to the younger mycelium. The cells of the hyphae in the young colonies are very minute but become somewhat larger as they grow older. The diameter of the filamentous hyphae is from 1.5 to 4.5 μ, while frequently a globose cell measures as much as 14 μ (fig. 20).

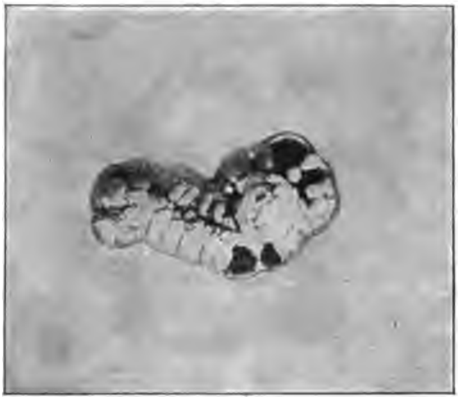
FIG. 19. CULTURE OF PLECTODISCELLA VENETA ON POTATO AGAR CONTAINING 1 PER CENT OF GLUCOSE

When the organism is cultured on potato agar containing glucose, the growth is much more rapid and aerial mycelium is formed which gives a pale brown or white downy appearance to the sclerotial growth. With the addition of glucose there is also a reduction, or at least a retardation, in the intensity of color production. On potato agar containing five per cent of glucose, the culture is pale brown with the characteristic red color developing next to the medium. On cornmeal agar the fungus has a brilliant red appearance, while on sterilized bean pods the growth is sclerotial and from cinnamon buff to maroon in color. On cellulose agar the fungus grows very slowly, there being only a slight digestion of the cellulose in the immediate proximity of the fungous mass.

Conidia are seldom produced in culture, and some difficulty was experienced in obtaining spores for use in inoculation experiments. It was found that a sudden change in the humidity of the culture brought about a production of conidia in sufficient numbers for use. It is to be noted, however, that the production of conidia is not continuous. The fungus was removed from a dry atmosphere to very moist conditions. This sudden change caused a production of conidia almost immediately, very similar to the manner in which they are produced in nature. Small conidiophores arise over the fungous mass and bear conidia which are similar to those occurring on the canes. When *Plectodiscella veneta* is grown continuously under moist conditions, few or no spores are produced.

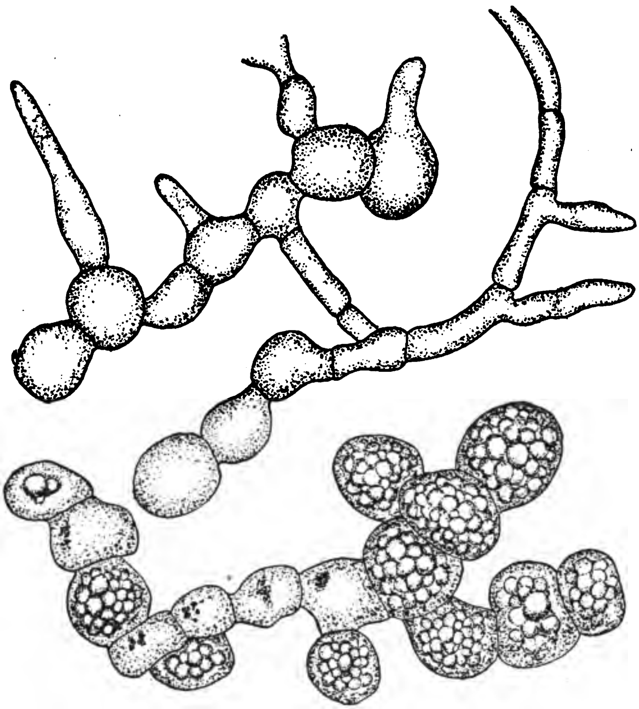

FIG. 20. MYCELIUM OF PLECTODISCELLA VENETA

The older cells are globose and usually filled with oil globules and red pigment. The mycelium is from a culture on potato agar. × 1132

INOCULATION EXPERIMENTS

Inoculations with spores from the Gloeosporium stage

The proof of the pathogenicity of the fungus depended on its constant association with the anthracnose until 1910, when Lawrence made a few inoculation experiments. He used the fruits of the blackberry, and inoculated them with conidia from the leaves and the canes. He was unable to obtain spores of *Plectodiscella veneta* in culture. Typical lesions were formed on the drupelets after an incubation period of from fifteen to forty-eight hours.

During the summer of 1913 the writer conducted a series of inoculation experiments on young raspberry canes of the Columbian variety, which were emerging from the ground. Cotton-plugged lamp chimneys were placed over these shoots, and when they were about six to eight inches high they were sprayed with a suspension of *P. veneta* conidia in water. The conidia were taken from the lesions on older canes, and in a few cases from pure cultures on potato agar, but in no case did more than thirty or forty per cent of them germinate. All inoculations were made in the evening, to avoid the evaporation of the drops of water containing the spores, and the lamp chimneys were allowed to remain over the young plants for two or three days. Check plants were used. Many of these experiments were destroyed, as they were conducted in a field which was being continuously cultivated. The final data obtained, therefore, were relatively few and scattered.

Inoculations were made on the following dates: May 26, June 20 and 23, July 16, 18, and 29, and September 1. Fifty-six of these experiments were completed but infection occurred only in eighteen cases. The incubation period was three days for seven experiments, four days for four, five days for five, and seven days for two. The shortest period was during the warmest weather, while during cool weather no infections occurred. Aside from climatic conditions, the causes of the low percentage of infection were possibly poor germination of the conidia, the drying of the drops of water, and the condition of the host plant. When the host tissue becomes hard, infection does not take place. Other factors, not sufficiently understood, no doubt entered into the experiments.

Inoculations with spores from the ascigerous stage

In order to make certain the connection between the ascigerous form and *Gloeosporium venetum* Speg., a series of inoculation experiments were conducted. The use of ascospores as an inoculum was impossible, since very few could be collected owing to the scarcity of the ascocarps and their irregularity in time of maturing. Also, it is difficult to make certain that the ascospores are separated from the conidia unless the former are collected by causing them to be ejected on plates of agar. The most satisfactory method appeared to be the use of conidia for inoculation from a culture of the fungus that had been developed from a single ascospore.

Such a culture was obtained, and was grown on three-per-cent potato agar until large, sclerotia-like masses were formed. These fungous masses were then transferred to sterilized bean pods in tubes containing several centimeters of water. The bean pods served primarily as supports on which the fungus could be placed above the water. The cultures were then placed in an incubator at a temperature of 24° C., and by the end of three days a sufficient number of conidia were produced. By dropping the fungous mass into a small quantity of water the spores readily fell off and could be sprayed on the infection court. The germination of these conidia was fairly rapid, a germ tube being developed in about five hours; but the proportion of germination was low, in most cases between five and ten per cent.

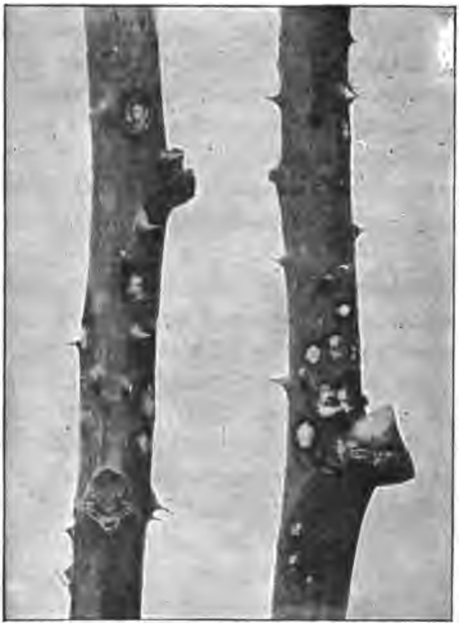

FIG. 21. ANTHRACNOSE LESIONS ON CANES OF BLACK RASPBERRY PRODUCED BY ARTIFICIAL INOCULATION

The canes were inoculated on April 15, 1915, with spores from a culture of *Plectodiscella veneta* which had developed from a single ascospore

Early in the winter of 1914–15 a number of roots of the Columbian variety of raspberry were planted in the greenhouse. Owing to the earliness of the dormant period and to the unfavorable conditions within the greenhouse, the plants grew slowly and gave a very stunted growth. All inoculation experiments with these plants gave negative results. As already stated, the anthracnose lesions appear only on tender succulent canes, and apparently the canes which had developed slowly on the green-house plants were too hard and woody for the fungus to infect.

Later, about the first of March, 1915, a few raspberry plants of a red variety, which were tender and growing rapidly, were procured. On March 4 two canes were sprayed with a suspension of conidia from a culture of the fungus developed from a single ascospore, and the canes were covered with bell glasses lined with moist filter paper. These glasses were plugged at the top with cotton and allowed to remain over the canes for two days before removing. Two other canes in the same bed remained untreated. On March 20, small purple spots had appeared on one of the canes. These infections grew slowly, much more slowly than an anthracnose lesion developing in the field, but spots typical of those caused by *Gloeosporium venetum* were produced. Microscopical examination of the spots showed conidia of *Gloeosporium venetum.*

Again on April 15 four tender canes of a blackcap variety of raspberry were sprayed with a suspension of conidia as above. Bell glasses were placed over them as in the previous experiments, and one check plant was used. A sample of the conidia used was placed in a drop of water on a slide, and about eight per cent of the spores germinated. After about a week, on April 21, a number of small purple spots had appeared on the four canes and these later developed into typical anthracnose lesions (fig. 21). The check plant remained normal.

Cross-inoculations

Although no cross-inoculation experiments were conducted to test the ability of the pathogene isolated from one species of Rubus to infect another species, some data regarding this are at hand. In the experiments described above, the culture of the fungus from a single ascospore was isolated from the hybrid known as *Rubus neglectus*. The pathogene then produced infection on both *Rubus occidentalis* and *Rubus idaeus* var. *aculeatissimus*. The cultural characters of the fungus isolated from these three species, as well as from the blackberry (*Rubus* sp.), are identical.

THE EFFECT OF WEATHER CONDITIONS

Practically nothing is known as to the exact effect the diseased canes have on the yield of fruit. No experiments have been conducted to determine the relationship and it is very difficult to estimate. Observations show, however, that the decrease in yield due to the disease varies considerably with weather conditions. This variation may be attributed largely to the fact that both the pathogene and the canes are biennial. The infection period of the fungus is during the early summer when the canes are in their first year's growth, while fruit is not produced until the second year. Therefore the weather conditions that prevail both throughout the infection period and at fruiting time influence the yield. If during the first year's growth of the canes there is an abundance of rain and damp cloudy weather, the young shoots in a field where the anthracnose exists become severely diseased. Such weather is effective only the first part of the season, as practically no infection occurs after July. Furthermore, if dry weather prevails the following year when the canes produce fruit, the berries mature under very unfavorable conditions. They are subject not only to the dry weather, but also to the diseased condition of the canes where the conductive tissue is impaired. It is during such combinations of seasons that the loss to the raspberry crop is so noticeable, while in a season when there is plenty of moisture the diseased canes may produce a good yield of berries.

Canes that are affected with anthracnose are, as a rule, more susceptible to winter injury than are unaffected canes. In a field in which the disease is present, the canes that are found to have been killed during the winter are the ones that were severely affected by anthracnose and other diseases.

CONTROL

CULTURAL METHODS

It has been observed by the writer that cultural methods greatly favor the distribution of the pathogene to the new raspberry plantings. The method of propagation of the blackcap and the purple-cane raspberry is no doubt accountable for this. These varieties are propagated by means of tip layers, which many growers do not remove in the spring until the young shoots have reached a height of a foot or more. By this practice it is maintained that the young plants are afforded a better chance of development. However, during this period the old diseased canes act as a source of inoculum to the new shoots, which become infected and thus the disease is carried to the new plantation. On the other hand, if care is taken to dig the roots before they sprout or before the fungus on the old canes sporulates, which in New York State is sometime near the middle of May, a healthy setting can be obtained. In the case of the red varieties, which it is necessary to propagate by means of suckers, the young plants should be procured from fields where it is known that anthracnose does not exist, or the canes should be carefully examined for lesions of the disease. The red varieties of the raspberry are very resistant, and therefore it is not uncommon to find a field free from the disease, from which young suckers may be selected. As a raspberry plantation is comparatively short-lived, the selection of healthy plants at the beginning is a long step in the control of the disease. Moreover, observations indicate that the pathogene does not spread rapidly from one field to another. The character of the fungus would further substantiate this view, as the sticky walls of the conidia render them not readily adapted to dissemination by the wind.

The eradication of anthracnose after it has once become established in a field is a difficult process. Pruning out the diseased canes has been recommended, but this is not desirable in the majority of cases since usually the disease has become widely spread before it is noticed and without the entire eradication of the sources of inoculum but little good can be accomplished. Sturgis (1900) cites an instance in which the majority of infected canes were removed and the disease was checked. The season was dry, however, and this probably accounts for the reduction in infection. No doubt the removal of old canes immediately after the fruiting season is good cultural practice, but from the standpoint of checking the disease it is beneficial only in obtaining better aeration. Thorough cultivation, especially the eradication of weeds, likewise is advantageous, or any measure that has a tendency to keep the canes free from persistent moisture.

SPRAYING

Numerous attempts have been made to control anthracnose by spraying, but the results in most cases have been questionable. Since he found the raspberry disease so similar to anthracnose of the grape, Scribner (1888) recommended spraying with iron sulfate when the plants were in a dormant condition, and using bordeaux mixture if subsequent applications were necessary.

Paddock (1897) conducted spraying experiments in a black raspberry plantation for three years with doubtful results. At least he came to the conclusion that spraying was not a profitable operation, but the data given by him may be interpreted otherwise. His experiments briefly are as follows:

The first three rows in the raspberry plantation were sprayed when dormant with copper sulfate, using three pounds to eleven gallons of water; the next three rows were treated with a saturated solution of iron sulfate in water; the last three rows were left unsprayed. This plan was repeated five times. The two treated series were then followed with five applications of bordeaux mixture. The yields of berries are given on the three series for three years. The spraying was begun in 1894, and therefore the yield in 1895 was the first on treated canes. The yield in that year was much increased over that of the preceding year. For the treated rows there was an increase of 171 per cent and 148 per cent, respectively, while for the check row the increase was only 39 per cent. In 1896 there was not such a great difference in the yields, but the infection, even on the check rows, was very slight. Paddock compared his data one year at a time and did not take into consideration the fact that the spraying of the canes one season affected the yield the following year. Therefore, with the present interpretation of the results obtained by Paddock, there seems to be a pronounced indication that spraying would be profitable, at least in years when the anthracnose infection is severe.

Rees (1915) claims that blackberry anthracnose in the northwestern United States can be controlled by spraying. This, however, is hardly comparable with spraying for the control of the same disease on the raspberry. The benefit derived from treating the blackberry plant is in preventing berry infection, while on the raspberry the fruit is never infected.

During the summer of 1911 Dr. P. J. Anderson conducted spraying experiments in raspberry fields at Brant, New York. This work was continued by J. H. Muncie during the summer of 1912, and by the writer during the seasons of 1913 and 1914, after which the experiments were brought to a close. A large number of spray materials, alone and in combination, were used. The results of the experiments were recorded for the most part on the basis of percentages of infected canes. This in itself is unsatisfactory, as it does not show the severity of infection and gives no indication as to the effect of the spray on the yield of fruit, which is really the ultimate aim. Thus very little data were obtained indicating that spraying was effective.

A few well-checked experiments, however, are worthy of recording. In two plats, each containing approximately one hundred and thirty-two bushes, three applications of bordeaux mixture, 4–4–50, reduced the number of diseased canes to 23 per cent and 16 per cent, respectively, while the untreated bushes showed infection to the extent of 77 per cent and 71 per cent, respectively. The first application was made when the young shoots were from eight to ten inches high, and the following applications were made at intervals of two weeks. These experiments were repeated for several seasons, with similar results. After the third application the ripening of the fruit prevented further treatments, although the lateral branches were not fully mature and occasionally during this period infections occurred. These infections were observed only in a few cases, however, and then they were not severe. Spraying after fruiting time is useless for several reasons. Infections seldom take place late in the season, and furthermore the new growth that develops after August is removed when the plants are pruned the following spring.

Besides bordeaux mixture various other chemicals were used. Lime-sulfur, self-boiled lime-sulfur, and iron sulfate were tested, but none of these gave satisfactory results. The adhesive quality of the iron sulfate in combination with the other spray materials also was investigated, but sufficient benefits were not observed to warrant recommending its use. Lime-sulfur, 1 gallon to 40 gallons of water, precipitated with iron sulfate, 7½ pounds to 100 gallons, gave a reduction in the percentage of infected canes. The spraying, however, dwarfed the plants considerably, causing them to bear small fruit with an insipid flavor. Bordeaux, on the other hand, caused only a slight burning of the tender leaves.

The application of a spray solution when the plants are in a dormant condition, as suggested by several investigators, was tested thoroughly during four seasons. Various strengths of iron sulfate, the greatest being 2 pounds of the material to 1 gallon of water, copper sulfate 4 pounds to 50 gallons of water, and lime-sulfur 1 to 8, proved to be of no benefit.

The chemicals evidently do not penetrate far enough into the lesions to kill the pathogene, or else they fail to remain on the plants for a sufficient length of time to prevent the fungus from sporulating. Although the iron sulfate did not injure the buds, it caused the canes to turn black, giving the plants the appearance of having been burned over by fire; but this caused no harmful effects to the plants. This blackening of the canes was observed on the Columbian variety, and whether or not it occurs on all varieties of the raspberry is not known.

The yield of berries was recorded in only one experiment. On two rows, with approximately sixty-six bushes each and with 44 per cent of the canes diseased, there were estimated to be about 360 quarts more per acre than on two check rows with 90 per cent of the canes diseased. The treated plat had been sprayed with bordeaux and was separated from the untreated plat by two rows. This is but an indication that spraying is beneficial, and no adequate conclusions can be drawn from so small an experiment. More data relating to the effect of diseased canes on the yield of the fruit are needed, and until they are obtained no conclusive proofs can be furnished that spraying to combat the anthracnose of the raspberry is a profitable practice.

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AGRICULTURAL EXPERIMENT STATION

AN INVESTIGATION OF THE SCARRING OF FRUIT CAUSED BY APPLE REDBUGS

HARRY H. KNIGHT

ITHACA, NEW YORK
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THE REFINEMENT OF FEEDING EXPERIMENTS FOR MILK PRODUCTION BY THE APPLICATION OF STATISTICAL METHODS

L. A. MAYNARD AND W. I. MYERS

The type of feeding experiment considered in this bulletin is that which involves a comparison of different feeds, in different combinations and in varying amounts, when fed to milch cows of different breeds, ages, and conditions. Such " practical " feeding trials have occupied a large place in the experimental work thus far performed in animal nutrition, and have contributed considerably to the art of feeding. In recent years, however, much criticism has developed regarding this type of study, and there are those who believe such work should be discontinued. The authors believe there is still a place for the practical feeding trial. However, no one is justified in conducting such an experiment without a thoro knowledge of the factors involved, of the limitations of present methods, and of the uncertainty attendant on the interpretation of results, due to individuality.

The subject matter of this bulletin comprises the results of a study along the foregoing lines, as preliminary to the beginning of some feeding trials with dairy cows at this station. It seemed that the data obtained should prove of some value to others who are conducting feeding trials.

STUDY OF METHODS OF CONDUCTING FEEDING EXPERIMENTS

THE PRACTICAL FEEDING TRIAL, ITS LIMITATIONS AND ITS VALUE

Feeding trials have been criticized on the ground that as means of solving problems in animal nutrition they have outlived their usefulness. McCollum (1916)[1] has pointed out that the results have been meager in proportion to the time and money expended. He states that it is the opinion of many animal husbandry men of wide experience that the present method of trying this or that concentrate as compared with another has taught about all it ever will teach. Evidently it is believed that there are better methods which should supersede the feeding trial. However, this view does not seem to be shared by the majority of investigators. Grindley (1915) is of the opinion that properly conducted feeding experiments are the most direct means of attacking many of the problems of the livestock farmer. Waters (1912) points out that feeding trials are the only means by which the application to farm practice of the results of fundamental experiments can be determined. He states that there is no royal road to this knowledge, and no shorter cut than actual trials with the kind of stock the farmer has to feed under the conditions prevailing on his farm.

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[1] Dates in parenthesis refer to bibliography, page 248.

That feeding trials with a given ration or condition have a limited application to other rations and conditions, is recognized. It is recognized also that the cost of properly conducted trials is high in proportion to the results obtained. Therefore, in studying the feeding value of a given feed or ration, it is essential to first study carefully the teachings of pure science and the results of any experimental work having a bearing on the problem, either in human or in animal nutrition. Next, feeding trials with small animals should in many cases be undertaken. Finally, if previous study and work have justified it, the actual trial with the animals in question should be made. Knowledge of the processes taking place in the animal body is at present too fragmentary to enable one to reason infallibly from pure science to feeding practice, or even from experiments with small animals to the feeding and management of the dairy cow. It is granted that there are more refined methods than the feeding trial, and it is believed that the former should precede and in many cases make unnecessary the latter. However, for the final proof of theories and of the validity of reasoning from small-animal experiments, the practical feeding experiment must serve until more is known of the fundamentals of animal nutrition.

Feeding trials have been criticized on the ground that they have been poorly conducted. It is charged that work along this line has fallen behind other branches of agricultural science, due to a lack of fundamental knowledge and a disregard of the teachings of pure science. Some critics have advocated the abandonment of feeding tests by the experiment stations for the reason that they can be carried out better by the farmers themselves. That these criticisms are in many instances just must be admitted. Inasmuch as there is still a place for the feeding test, it is evident that investigators should so improve their methods as not to invalidate their conclusions by faulty procedures or fallacious interpretation of results.

FACTORS TO BE CONSIDERED IN PLANNING A FEEDING EXPERIMENT

In planning a feeding experiment the investigator aims to have equality in all the conditions except one, which is the factor to be studied. Because of the complexity of biological processes this is practically an impossible goal. In discussing experiments with living organisms, Blackman (1905) states that the investigator who tries to evaluate exactly the effect of a single factor on a multi-conditioned metabolic process faces an almost impossible task.

Controllable factors

In a feeding experiment certain factors can be definitely controlled — such as the kind and quantity of the ration, the method and time of feeding, the general care and management of the animals. Certain other factors cannot be entirely controlled because they are due to the individuality of the animals; however, the effect of these factors may be greatly lessened by so choosing from animals of known history as to obtain a group as nearly alike as possible with respect to records and previous treatment. It is unnecessary to enter here into a discussion of the factors that may be eliminated by a careful selection of animals. A thoro treatment of this subject has been given in the report of the American Society of Animal Nutrition (1909), and by Waters (1912), Morse (1913), Mitchell and Grindley (1913), and Grindley (1915).

Uncontrollable factors

When as many factors as possible have been eliminated or equalized by a proper selection of animals, there still remain certain causes of variation which cannot be eliminated. These causes comprise feeding capacity, productive capacity, physiological peculiarities, and other functional characteristics rendering one animal distinct from another. Thus it is seen that the general proposition — equalization of all factors except one — is impossible of realization. There must always be certain variables, due to individuality, which cannot be controlled. However, the probable limits of variation of these factors may be determined by the application of statistical methods. Thus, in planning feeding experiments, one should make use of statistical data which have been accumulated as to the probable error due to individuality. At the end of the experiment a statistical analysis of the results should be made, before any interpretation is placed on them.

VARIABLE FACTORS WITH SPECIAL REFERENCE TO MILK PRODUCTION

In addition to the factors that have been discussed as causing variation in any feed experiment, there are certain specific variables which become operative when trials with milch cows are concerned, due to the physiological processes involved. These specific factors make the prosecution of an experiment in milk production more difficult than one in which gain in weight is the object desired, not only as regards the selection of animals and the control of conditions but also in respect to the interpretation of results. It seems desirable to enter into some discussion of these factors.

In feeding for flesh production an increase in the whole body of the animal is sought, and all feed consumed above that used in maintenance is available for such production. In feeding milch cows, however, the secretion of a single set of glands is the object desired. An increase in body weight in a dairy cow may take place, but it is undesirable, particularly in a feeding experiment. It results in the use of the ingested food for other purposes than milk production, and any considerable fattening tends to check the activity of the mammary glands. Thus, improper rations not only may limit the quantity of milk produced, but also may deflect production from milk to flesh.

Milk secretion is a less understood process than flesh production and is much more subject to disturbing factors and to wide variation. In this connection Armsby (1917:500) states:

> The feeding of a milking animal is in a certain sense a secondary factor in dairying. The possibilities of successful milk production depend primarily upon the capacity of the animals as milk producers and upon the maintenance of such an environment as will give free play to this capacity. Feed . . . cannot greatly stimulate production, though it may limit it for lack of material. . . . Improper rations, . . . , even if sufficient in quantity, may if deficient in quality deflect production from milk to fattening, or possibly to greater muscular activity, and thus fail to utilize fully the milk-producing capacity of the animals.

Milk secretion is a periodic function, having as its object in nature the nourishment of the young. The length of a lactation period varies with different animals, and with the same animal in different years. The decrease in production during a lactation period is also a variable factor. The rate of decrease may vary widely at different stages in the same animal, and may vary from year to year at a corresponding period of lactation. Marked irregularities are frequently shown which cannot be explained by any observed conditions. Toward the end of the lactation period, whether a cow is with calf becomes an important consideration. Gavin (1913 a) has shown that the fall in milk yield due to fetal growth begins from nine to twelve weeks after service. At from seventeen to twenty weeks a decrease of roughly ten per cent was found, and about twenty-five per cent at from twenty-five to twenty-eight weeks.

Hills (1896) has found variations in yield due to time of calving. He found that a fall cow maintains her production better than does a spring cow, and produces milk of uniform fat content. On the other hand, a spring cow betters the quality of her milk beginning five months after calving, while this was found to be the case with a summer cow at the end of three months. Hills found that abortion causes a shrinkage of one-third in milk yield, and a gain of one-tenth in quality, as compared with the production of the previous lactation.

The plane of nutrition is an important factor in feeding experiments, because an increase in weight usually begins before the maximum capacity for milk secretion is reached. Thus, on heavy rations both flesh production and milk production take place, while on light rations the former may not occur.

A review of these factors, which specifically cause variation in feeding experiments for milk production, must convince one of the especial need of careful selection of animals and control of experimental conditions in such trials. The necessity of the application of statistical methods to the interpretation of results must also be evident.

METHODS OF CONDUCTING FEEDING EXPERIMENTS WITH MILCH COWS

In attempting a study of the probable error attendant on feeding experiments with milch cows, it is necessary first to consider two rather distinct procedures that have been used in such experiments. In carrying out feeding trials, usually either the alternation or the continuous system has been employed. A considerable survey has been made of the literature of the subject, in order to determine the extent of the use of each of these systems and the evidence regarding their relative merits.

The alternation system

In the alternation system competitive rations are fed to the same group of cows in successive periods — Ration A followed by Ration B, this in turn followed by Ration A, and so on. This system appears to have had the widest use both at the American experiment stations and abroad. Hills has conducted extensive experiments with dairy cows since 1887. The extensive nature of these experiments as regards time, coupled with the large number of animals that have been available, has enabled this investigator to make a thoro study of experimental methods. Detailed accounts of this work are given in the annual reports of the Vermont station from 1887 to 1908. Among other features an exhaustive study has been made of the alternation system and modifications of it. The results of the observations of twenty years are embodied by Hills in a paper published in 1907.

Hills has made considerable study relative to the most satisfactory length of the feeding period in the alternation system. He believes that periods of from two to three weeks are too short. He points out, however, that making the periods as long as eight weeks seriously curtails the number of periods. A feeding period of five or six weeks is favored.

For the sake of eliminating the influence of seasonal variations, Hills has used two groups of animals — Group I receiving Ration A during the period when Group II received Ration B, and vice versa.

Hansen (1906, a and b, 1908, 1911, 1914) has used the alternation system in experiments extending over ten years. His method differs somewhat from Hills' in that no ration was used twice except the basal ration, which was fed during the first and the last period in order to show the decrease in production due to the advancing lactation period. Hansen used feeding periods of fourteen days in most of his work.

Morgen and his coworkers (1905, 1906, 1907) have conducted extensive experiments with sheep and goats relative to milk production, using the alternation system. The feeding periods varied from three to four weeks, about half this time being preliminary. These investigators did not use any ration more than once in a given experiment, except the basal ration. In some experiments the latter was fed during the first and the last period, in others it was alternated with the different trial rations.

A considerable number of other investigators have used the alternation system rather extensively. The work of the men referred to in the preceding paragraphs is cited as typical of experiments conducted under this system and as illustrating certain common variations in procedure. Further examples appear unnecessary.

The continuous system

In the continuous system competitive rations are fed to two groups of cows continuously — Ration A to Group I and Ration B to Group II. An essential feature of this system is that the groups shall be so made up as to be of equal productive capacity. Therefore the question of the selection of animals is of prime importance. Feeding periods have varied from two months to an entire lactation period or longer, according to the investigator.

Haecker (1914) has used the continuous system in experiments relative to milk production extending over the years 1902 to 1909. He used from eight to ten cows in a group, and the feeding trials extended over two or three months. Among other investigators who have made considerable use of the continuous system may be mentioned Williams (1904), Fraser and Hayden (1912), Caldwell (1913), Davis (1915), and Woll, Humphrey, and Oosterhuis (1914).

The combined continuous and alternation system

Hills has tested a system which he calls the combined continuous and alternation system. In this scheme three groups of animals, equal as regards probable productive capacity, are made up. To one group the basal ration is fed continuously, to the second group the trial ration is fed continuously, while the third group is alternated on the two rations.

As a result of six years trial Hills (1907) advances the opinion that this scheme is inferior to the simple alternation system, particularly if only a small number of animals are available.

Relative merits of the three systems

The advantage of the alternation system lies in the fact that the trial of the two sets of rations with the same animals eliminates many of the factors due to individuality and obviates uncertainties in attempts to make up groups of like production. On the other hand, the use of the alternation system necessitates a short feeding period. Hills (1907) recognizes this disadvantage. In this connection he quotes Babcock as follows (page 117 of reference cited):

> It seems likely . . . that there are certain reserve forces which enable an animal to adapt itself to adverse conditions and even to overcome the effect of malnutrition for much longer periods than have heretofore been considered sufficient. . . . Much additional knowledge concerning the physiological influence of foods may be gained, and thereby many of the uncertainties which exist to-day regarding feeding problems be eliminated, by greatly extending the experimental periods.

Thorne, Hickman, and Falkenbach (1893:82), after two years use of the alternation system, say: "We need to expand the 90-day test into a 12-month test . . . We might as well drop the three or four-week test altogether."

Another disadvantage of the alternation system results from the residual effect of a given ration on a succeeding one. Armsby states (1917:525): "It is not an unusual experience in dairy feeding experiments to see a change of rations followed by a temporary stimulation of the milk production which is not sustained."

Woll (1904) states that any change in the system of feeding is generally accompanied by an immediate disturbance of the normal character of the production of the cows, and that several weeks may be required for adjustment. Those who have used the alternation system have endeavored to offset this residual effect by the use of a preliminary period. However, these periods have unquestionably been too short in most cases. Indeed there is a question whether, when a ration has been used which reduces a cow's production considerably below normal, the cow can be brought back to normal production during the given lactation period. Soule and Fain (1905), speaking of their use of the continuous system, state that, tho they recognize its defects, they consider it preferable to the alternation system because of the time required to get a cow under the influence of a given foodstuff.

The continuous system obviates the disadvantages of the short feeding period and the residual effect. On the other hand, in this system questions arise as to the equality of individuals and groups selected on the basis of probable productive capacity. From the discussion of the factors causing variation in milk production, the great uncertainty involved in selecting groups of equal production is evident. In this connection Hills (1907) states: " He who can, from an often limited number of animals, formulate groups which for a great length of time will prove essentially equivalent in their milk-making powers is gifted with second sight." This is a very serious disadvantage of the continuous system. However, this difficulty should be minimized by the application of statistical methods. The variable factors due to individuality cannot be eliminated, but the probable limits of variation can be ascertained.

CONSIDERATIONS IN GROUPING EXPERIMENTAL ANIMALS

In selecting two groups of animals for use in an experiment conducted under the continuous system, it is clearly recognized that the two groups should be as nearly alike as possible. Points that must be considered are: previous treatment and history, age, stage of lactation, breed and type, productive capacity.

In this connection it is believed that a consideration to which insufficient attention has been given is that of history as regards diseases. A diseased animal is not normal and should not be included in a feeding experiment. It goes without saying that an animal used in experimental work should pass the tuberculin test. The herd records should furnish data as to abortion and breeding troubles, in order that animals abnormal in these respects may be excluded. Finally, it is believed that each individual selected for experiment should be given an examination by a veterinarian as to general health.

Considerable study has been made of the experimental work that has been done in regard to productive capacity, in an attempt to ascertain the points considered in selecting animals on this basis. The majority of investigators, however, have made little mention of the matter, and most frequently one finds merely the statement that " groups of equal production were chosen." Usually milk production is meant. Occasionally one finds the statement that groups were made equal as regards both milk and fat production. Just how this would be possible within very close limits with only a moderate number of animals to select from is not clear. Another ambiguous point is, just what is meant by " equal production." No statement has been found of the limits that have been allowed in choosing equal groups on the basis of production records.

Some investigators have selected groups on the basis of yield during the previous lactation period. That this alone is a poor criterion is shown by the work of Gavin (1913b). He found that the estimation of one lactation yield from another cannot be made with great accuracy, since the correlation coefficient between successive lactations does not rise above + 0.576 ± 0.025. As a result of an extensive statistical study, Gavin (1912) suggests the use of the " revised maximum " as a figure to describe the milking capacity of a cow. This figure is the maximum daily yield, three times reached or exceeded. The figure bears a close relation to the total yield of a normal lactation and shows rather less variation than the total. Gavin states that the figure is independent of length of lactation and time of service, and is not greatly influenced by general environment.

Instead of selecting animals on the basis of production in a previous lactation period, groups may be made up by considering the production in the same period before placing the cows on experiment. Caldwell (1913) fed a certain number of cows for thirty-one days on a basal ration, and then made up groups for a feeding test on the basis of production during that period. It is believed that this scheme is much better than the one based on the yields of a previous lactation. However, some consideration of the latter seems desirable in order that abnormal cows may be excluded. Fraser and Hayden (1912) report that they consider both present records and previous production in forming groups.

SUMMARY

From this study of the methods of conducting feeding experiments, it appears that the practical feeding trial still has its importance. Refined methods are, however, desirable. A more thoro knowledge and appreciation of the special variable factors involved in milk production is also essential. The continuous system of carrying out feeding tests would seem to be the more satisfactory method, provided the probable limits of variation over the experimental period can be ascertained. In selecting animals for an experiment the previous records and history of treatment and behavior should be consulted, in order that animals abnormal in these respects may be excluded. This selected group of animals should be fed the basal ration for a preliminary period, and should receive for that period the same care and management as tho on experiment. On the basis of production and behavior during the preliminary period, the selection and grouping of animals for the experiment should be made. The group selected for the preliminary period should contain a somewhat larger number of animals than will be required for the experiment, in order to allow a certain range in selection. In choosing animals for both the preliminary period and the experimental period, as many of the variable factors should be eliminated as is possible in consideration of the number of animals at the investigator's disposal. There will always remain a certain number of uneliminated factors, the probable limits of variation of which must be known for the intelligent interpretation of results. Thus statistical data relative to the variation in milk production under various conditions of selection are needed.

STATISTICAL STUDY OF VARIATION IN MILK PRODUCTION

OBJECT AND METHODS

The object of this statistical study, as has already been pointed out, was to obtain the data needed for the intelligent planning of feeding experiments conducted under the continuous system. These data consist primarily of information as to the probable limits of variation, over a given experimental period, of individuals and groups selected on the basis of equal productive capacity as determined in a preliminary period. It has been pointed out that variation can be lessened by so selecting the animals as to eliminate certain controllable factors affecting milk production, and that the number of factors which can thus be fixed is determined by the number of available animals from which the selection is made. Therefore data as to the effect of various selective factors on variation are needed, to attain the object of this statistical study.

The data for this study were obtained from the records of the university herd. These records are complete over a period of thirty years, and comprise data for some four hundred individuals. For the purpose of this study it would be desirable in some respects to have all the records from one calendar year, in order that all animals might be under the most uniform conditions of feeding and environment. This was of course impossible because of the large number of animals required for the study. However, the care and management of the university herd have been in accordance with the same general principles for the period of years represented by the data used. The records have made possible the exclusion from the study of all animals that have been used in any feeding experiment. It may be stated that animals on experiment are accorded more uniform treatment than the general herd, which is used for teaching purposes, and a greater degree of exactness would result if the data were obtained from records of such animals. But it was obviously impossible to make the present study from experimental records. In fact, if the data were thus obtained, they would be applicable only to investigations in which an experimental herd, separate from the general herd, was available. It is therefore believed that the data obtained in the present study have a wider application.

The breeds used in making this study were the Holstein-Friesian and the Jersey. The greater proportion of the work was done with the former breed, because the records of a much larger number of individuals were available. No study was made of groups comprising different breeds, because it is considered undesirable to use animals of different breeds in a feeding experiment under any conditions.

It has been stated that data were to be obtained as to the variation in an experimental period of individuals and of groups selected on the basis of their production during a preliminary period. Nearly all the studies included in this bulletin are concerned with milk production. The word *production* will therefore mean milk production unless otherwise designated. In order to get comparable and reliable results, a period of definite length, during which the records should be studied, was required. A twenty-weeks period was accordingly chosen, consisting of a two-weeks preliminary period and an eighteen-weeks experimental period. It must not be assumed that eighteen weeks is considered the best duration for an experimental period. It is believed that this period should be as long as the uniformity of conditions prescribed at the beginning of a given feeding trial can be maintained. Twenty weeks was found to be the longest period, between the time of freshening and the time when the animals went on pasture, for which any considerable number of records could be obtained. To combine records of animals on winter feeding with those of animals in pasture would introduce a rather serious irregularity. It therefore seemed desirable to limit the study to a twenty-weeks period for a given lactation, and the results obtained must be considered with respect to the period used.

In a part of this study the records of cows freshening between August 15 and December 15 were used, and the twenty-weeks period was begun exactly one month after calving. This eliminated the period during which many cows were on test. Under this plan all the records were from cows in the same stage of lactation, thus eliminating any variation due to difference in this respect. It was realized, however, that under experimental conditions — even tho, with a sufficient number of animals to choose from, a group freshening at approximately the same time could be made up — the exactness prescribed above could not be obtained. Accordingly, in another part of the study the twenty-weeks period was started on January 1 of a given year, using cows that had freshened in the preceding summer or fall. It is believed that this scheme approximates that of the ordinary feeding experiment.

In grouping together cows of equal productive capacity on the basis of the preliminary period, the question arose as to what constitutes "equal production." Inasmuch as no information on this point was found in the accounts of feeding experiments, arbitrary limits had to be chosen.

A range in milk production not exceeding 50 pounds for the two-weeks period was the basis of selecting classes of individuals of like production in most of the work. The limits, in terms of number of pounds yield for two weeks, were therefore as follows: 200–249, 250–299, and so on. By this system the percentage of range allowed was greater with groups of small production. In order to ascertain whether this variation had any appreciable effect, a percentage system was used in part of the work; a range of 10 per cent was allowed, and the limits became 200–219, 220–241, and so on.

In measuring the variation in production, during the eighteen-weeks period, of individuals and of groups selected on the basis of production during a preliminary period, the coefficient of variability[2] was the constant employed. This constant is the standard deviation of the individual production expressed as a percentage of the arithmetical mean production.

The probable error of each coefficient of variability was computed, in order to have a statistical measure of its reliability. The accuracy of a given coefficient of variability as a measure of the variation of the groups or the individuals it represents, depends on the number of groups or of individuals. The probable error of a given coefficient defines the limits above or below the computed coefficient within which the true coefficient has an even chance of falling. If the coefficient of variability of the individuals in a given group is found to be 10 per cent and its probable error is ± 1, the chances are exactly even that the true coefficient of variability of this group will fall between nine and eleven per cent.

In the preceding paragraphs the general methods used in this work are outlined. Certain other procedures have been followed in special cases, accounts of which are given under the cases in question.

STUDIES OF HOLSTEIN RECORDS: COWS IN UNIFORM STAGE OF LACTATION

The animals used in this part of the study freshened between August 15 and December 15, and the twenty-weeks period was started one month after calving. The results of this selection furnish records of animals uniformly advanced in their period of lactation and similar as regards the season in which the twenty-weeks period was chosen. The object of the study was to determine the normal range of individual and group variation under these conditions, and to determine the effect of certain other factors of selection on variation.

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[2] In this bulletin no attempt has been made to discuss the theories of the various statistical measurements employed. For a full discussion of the theories of variation and probable error, the reader is referred to the following standard works on statistics: *Statistical Methods* (1914), by C. B. Davenport; *An Introduction to the Theory of Statistics* (1912), by G. U. Yule.

Individual variation

The records were first divided into classes of individuals of uniform production for two weeks, all the individuals of similar production being put in the same class. The limits of each class had a range of 50 pounds, these limits being 250–299, 300–349, and so on. The variation of individuals within these classes is shown in table 1:

TABLE 1. INDIVIDUAL VARIATION

Class production, two-weeks period (pounds)	Number of individuals	Coefficient of variability during eighteen-weeks period
250–299	8	15.74 ± 2.65
300–349	11	14.66 ± 2.11
350–399	17	13.39 ± 1.55
400–449	13	12.40 ± 1.64
450–499	28	11.14 ± 1.00
500–549	31	10.02 ± 0.86
550–599	20	11.26 ± 1.20
600–649	23	9.53 ± 0.95
650–699	9	14.60 ± 2.32
700–749	8	10.88 ± 1.83
750–799	6	17.53 ± 3.41
800–849	4	11.69 ± 2.79
Total	178	....
Average[*]	....	11.87 ± 0.43

[*] The average coefficient here given is the weighted average of the coefficients of the different classes of individuals. In spite of the recognized shortcomings of any method of averaging coefficients of variability, it is believed that this procedure gives a fairly trustworthy idea of the variability of the individuals it represents. All average coefficients used in these studies are weighted averages.

In order to check the accuracy of the average coefficient as the measure of individual variability of the individuals here included, the coefficient of variability was computed from the weighted average standard deviation and the weighted average mean of the classes in the table. This method gave a coefficient of variability of 11.72 ± 0.42. The close agreement of this coefficient with the average coefficient indicates the essential accuracy of the method used.

The probable error of the average coefficient of variation is the weighted average of the individual probable errors. It is computed by weighting each probable error, squaring these products, summing, extracting the square root, and dividing by the number of probable errors.

The results shown in table 1 indicate the approximate range of variability, during an experimental period of eighteen weeks, of cows of similar productive capacity as indicated by their production for a trial period of two weeks. The coefficients of variability range from 9.53 to 17.53 per cent for individuals in the different classes, the average value for the 178 individuals being 11.87 ± 0.43 per cent. It is seen that both the high producers and the low producers show a somewhat greater variability than the middle classes. However, no conclusion can be drawn from this, because none of the differences are significant when their probable errors are considered.

Group variation

In the ordinary feeding experiment, groups of cows of equal total production are made up for the competitive rations. Therefore a study of group variation is important. It is possible, of course, to compute the probable coefficient of variability of a group of given numbers, given the coefficient of variability of the individuals. However, there were reasons why it seemed desirable to make a statistical study of group variation. In the first place, the calculated value on the basis of individual variation could thus be checked up. Further, a study of group variation was found to be the best method of studying the influence of various selective factors considered in forming groups.

In most of the work on group variation the groups were made up of six individuals. This was found to be the most convenient grouping with the records at hand, and it represents the typical-sized lot used in feeding trials. Some comparative studies were made of groups of various sizes. In making up lots of equal production on the basis of the preliminary period, a range of 100 pounds in the total production of the groups was allowed. Some study was made, however, of the effect of varying this range.

Variation in groups of unselected individuals.— Groups were made up of individuals taken at random, the only consideration being that the total production of each group for the preliminary period should fall between 3200 and 3299 pounds. The results of the study of variation in these groups are shown in table 2:

TABLE 2. VARIATION IN GROUPS OF UNSELECTED INDIVIDUALS

Group production, two-weeks period (pounds)	Number of groups	Number of cows per group	Coefficient of variability
3,200–3,299	33	6	5.09 ± 0.42

From the results shown in table 2, it is evident that the variation of groups of cows selected in this way is much less than for individuals as shown by table 1. The relation of individual variation to group variation is shown by the formula $\frac{c}{\sqrt{n}} = C$, in which c is the coefficient of variability of individuals, C the coefficient of variability of groups, and n the number of individuals in a group. Using the average coefficient of variability of individuals as shown in table 1, and solving this equation for groups of six, it is found that the coefficient of variability of a group of this size would be 4.84 per cent. This computed coefficient[3] checks closely with the coefficient found by actually testing groups of six, as shown by table 2.

Variation in groups of individuals of equal production.— In the preceding study no attention was given to the production of individuals except in so far as was necessary to make up groups of like production. It seemed desirable to determine the effect on group variation of selecting animals of equal individual production. The range allowed for individual production during the two-weeks period was 50 pounds. Groups of six of these equal individuals were so selected as to allow a 100-pound range for the group. The results of the study of their variation are shown in table 3:

TABLE 3. VARIATION IN GROUPS OF INDIVIDUALS OF EQUAL PRODUCTION

Individual production, two-weeks period (pounds)	Group production, two-weeks period (pounds)	Number of groups	Coefficient of variability
450–499	2,800–2,899	4	1.90 ± 0.45
500–549	3,100–3,199	5	3.58 ± 0.76
600–649	3,700–3,799	4	3.38 ± 0.81
Total	....	13	....
Average	....	....	3.00 ± 0.41

It is seen from the table that the average coefficient of variability of groups of like individuals is 3.00 ± 0.41, as compared with 5.09 ± 0.42 for groups of unselected individuals. The difference between these two values is 2.09. In order to determine the degree of reliance that can be placed on this difference, its probable error should be computed. The probable error of the difference between two coefficients of variability is the square root of the sum of the squares of the probable errors of the coefficients under consideration. The probable error of the difference just given is ± 0.59, and the difference, with its probable error, would be expressed as 2.09 ± 0.59. If the probable error were exactly as large as the difference, the chances would be even that a repetition of the study would result in lower variation for similar individuals, and likewise even that the opposite result would be obtained. The difference under discussion is 3.5 times its probable error. The odds are therefore about 54 to 1 that a repetition of the study would give similar results. Wood and Stratton (1910) have suggested that for data obtained from agricultural experiments, odds of 30 to 1 may be considered as conclusive evidence. Odds of 30 to 1 require that the difference must be 3.17 times its probable error. The data given in this case more than satisfy the requirements suggested by Wood and Stratton, and it may therefore be concluded that groups of cows of similar individual production are less variable than groups of unselected animals.

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[3] The range of 100 pounds allowed in selecting groups of equal production is not proportional to the range of 50 pounds allowed in selecting individuals of equal production. The results of studies described elsewhere in this bulletin, however, indicate that such variations in the range allowed in selecting groups or individuals of equal production do not have any appreciable effect on variation in milk production during the experimental period.

As a further test of the effect of selecting equal individuals, groups were made up whose total production for two weeks was from 3200 to 3299 pounds but which were divided into three classes according to individual production. The individuals of Class I had productions of from 500 to 599 pounds for the trial period; those of Class II had productions of from 400 to 499 pounds or from 600 to 699 pounds; those of Class III had productions under 400 pounds or over 699 pounds. By means of this method of selection, there were made available groups of six cows of similar total production, divided into three classes according to the similarity of the individuals as shown by their production during the trial period. The results of this selection are shown in table 4:

TABLE 4. EFFECT OF SIMILARITY OF INDIVIDUAL PRODUCTION ON VARIABILITY OF GROUPS

Class	Individual production, two-weeks period (pounds)	Group production, two-weeks period (pounds)	Number of groups	Coefficient of variability
I	500–599	3,200–3,299	9	2.98 ± 0.47
II	400–499, 600–699	3,200–3,299	11	4.84 ± 0.70
III..........	Below 400, above 699	3,200–3,299	12	5.27 ± 0.73

The difference in variability between the groups of Class I and those of Class II is 1.86 ± 0.84. Here the difference is 2.21 times its probable error, and the odds are 6 to 1 that the difference in variability is due to the factor of selection. The difference in variability between the groups of Class I and those of Class III is 2.29 ± 0.87. Here the difference is 2.63 times its probable error, and the chances are 12 to 1 that groups of individuals of similar productive capacity are less variable. The consistency of the results listed in tables 3 and 4 seems to indicate that similarity of individuals in productive capacity has an important effect on variability of the group, and that in grouping cows for a feeding test the experimental error can be reduced by using similar individuals.

Age of cows as affecting variability.— In selecting animals for experimental purposes, it is desirable to know whether groups of cows of the same age are more variable or less variable than groups of cows of different ages. Groups of cows of the same age were made up and their variability was compared with that of groups made up without regard to age. The results of this study are shown in table 5:

TABLE 5. EFFECT OF AGE OF COWS ON VARIABILITY OF GROUPS

Number of lactation	Group production, two-weeks period (pounds)	Number of groups	Coefficient of variability
First	2,300–2,399	8	2.93 ± 0.49
Second	3,200–3,299	5	2.77 ± 0.59
Third	3,400–3,499	4	2.27 ± 0.54
Fourth	3,900–3,999	4	3.10 ± 0.74
Total	....	21	....
Average	....	....	2.77 ± 0.29

The coefficient of variability of groups of cows of different ages is shown in table 2 (page 226) to be 5.09 ± 0.42. A comparison of this value with those of groups of individuals of the same age shows that the latter are less variable. The difference between the average coefficient for cows of the same age and that for cows of different ages is 2.32 ± 0.51. The odds are about 400 to 1 that the difference is significant.

It is not shown in table 5 that cows are less variable at any particular age in so far as the ages covered by the table are concerned. Specifically there is no evidence that heifers are more variable than older animals. This should not, however, be considered an argument for using heifers in a feeding trial. The great disadvantage in using immature animals is that, inasmuch as part of their food is used for growth, no quantitative conclusions can be drawn as to the effect of a given ration on milk production.

Allowable range in selecting groups of equal production.— Another important consideration in making up groups for feeding trials is concerned with the interpretation of the term *equal production*. In this connection the questions arise as to how closely the production of two groups must agree to be considered equal, and as to the effect on variability of changes in the range. In order to get information on these points, the records were first divided into groups of six, the total production of each of which fell within the limits of from 3200 to 3299 pounds. These groups were then divided into two classes of equal production, their limits being from 3200 to 3249 pounds and from 3250 to 3299 pounds, respectively. The same groups were next divided into four classes of equal production, the limits of which were from 3200 to 3224 pounds, from 3225 to 3249 pounds, from 3250 to 3274 pounds, and from 3275 to 3299 pounds, respectively. Finally the groups were divided so as to have a 10-pound range, as from 3200 to 3209 pounds, from 3210 to 3219 pounds, and so on. The results of this study are shown in table 6:

TABLE 6. EFFECT ON VARIABILITY OF CHANGES IN RANGE OF GROUPS

Group production, two-weeks period (pounds)	Range allowed by group limits (pounds)	Number of groups	Coefficient of variability
3,200–3,299	100	33	5.09 ± 0.42
3,200–3,249 3,250–3,299	50	33	5.03 ± 0.42
3,200–3,224 3,225–3,249 3,250–3,274	25	31	4.88 ± 0.43
3,200–3,209 3,210–3,219 3,240–3,249	10	20	4.60 ± 0.52

The coefficients in table 6 decrease slightly as the group limits are narrowed. The consistency of the results suggests the probability that the narrowing of the limits is responsible for the decrease. However, the difference between the highest and the lowest limits is not so great as its probable error, and therefore no significance can be attached to it. It would appear that if there is any decrease in variability caused by lowering the range allowed by the limit below 100 pounds, it is so slight that there is no object in using the narrower limits.

Size of group as affecting variability.— It has been stated that group variability decreases according to the square root of the number of individuals in the group. A short study was made of groups of different sizes, merely to compare the observed values with the calculated values and thus check the accuracy of the methods used. The values calculated for groups of different sizes from the figure for individual variation, as found in table 1, were compared with the observed values for groups of three different sizes. The results are shown in table 7:

TABLE 7. EFFECT OF SIZE OF GROUP ON VARIABILITY

Group production, two-weeks period (pounds)	Number of groups	Number of cows per group	Coefficient of variability	
			Observed value	Calculated value
4,400–4,499	23	8	4·33 ± 0·43	4·19
3,200–3,299	33	6	5·09 ± 0·42	4·84
1,800–1,899	49	4	5·39 ± 0·37	5·94
2,100–2,199				
2,300–2,399				

A comparison of the observed and the calculated coefficients of variability for groups of eight, six, and four individuals, given in table 7, shows close agreement between the two values in each case. In two cases the calculated values are within the limits set by the probable errors above or below the observed coefficients. In the third case the variation is not significant. This indicates that the data are trustworthy and that in a similar way the probable coefficients of variability for groups of different sizes may be computed from the coefficients of variability of individuals.

Selection of groups on the basis of production during the preceding lactation period.— It has been stated that the selection of groups on the basis of yield during the preceding lactation period must be considered a poor method. Inasmuch as several investigators have selected groups on that basis, it seemed desirable to make some study of the method. Accordingly, groups of six cows each were formed on the basis of their productive capacity as shown during the preceding lactation period. The results of this study are shown in table 8:

TABLE 8. VARIATION OF GROUPS SELECTED ON THE BASIS OF PRECEDING LACTATION RECORDS

Group production during preceding lactation period (pounds)	Number of groups	Coefficient of variability
60,000–61,999	17	9.11 ± 1.05

A comparison of the coefficient shown in table 8 with the value 5.09 ± 0.42, given in table 2, indicates that when groups of cows are selected on the basis of their yield during the preceding lactation period the coefficient of variability is nearly double that for groups selected on the basis of a two-weeks preliminary period in the same lactation period. It is thus proved that the latter is by far the better method.

Variation of groups in fat production.— All the preceding studies have been made with regard to milk production only, since that is the factor given the greatest consideration in feeding trials. It seemed desirable to ascertain whether the variation in fat production is similar to that in milk production. In order to determine the variability of groups of cows in fat production, groups were made up of cows having approximately equal fat production. Since 100 pounds of milk was the range allowed in the group limits in studying variation in milk production, a corresponding range of 3.5 pounds of fat was allowed in the group limits in this study, this being the approximate amount of fat in 100 pounds of average Holstein milk. The results are shown in table 9:

TABLE 9. VARIATION OF GROUPS IN FAT PRODUCTION

Group production, two-weeks period (pounds)	Number of groups	Coefficient of variability
107–110.4	33	5.13 ± 0.43

It is seen from table 9 that the coefficient of variability for fat production is practically identical with the value shown in table 2 for milk production.

STUDIES OF HOLSTEIN RECORDS: COWS IN VARIOUS STAGES OF LACTATION

As has been pointed out, the beginning of an experiment on a selected date, using cows that have freshened during the preceding six months, represents the procedure usually followed in a feeding experiment. Therefore studies were made of records taken on this basis in order to furnish data as to variability under this method of selection and to obtain information by comparison with the results of the preceding method of selection as to the effect of stage of lactation on variability. The general methods used in these studies were the same as those employed in the former ones, except that, as previously stated, the time elapsing between freshening and the beginning of the twenty-weeks period was not fixed.

Individual variation

The individual cows were here, as before, divided into classes of approximately similar individual production. Inasmuch as the cows were in different stages of lactation, the average number of weeks after calving is given for each group. The results of this study are shown in table 10:

TABLE 10. Individual Variation

Individual production, two-weeks period (pounds)	Average number of weeks after calving	Number of individuals	Coefficient of variability
200–249	14	5	30.08 ± 6.42
250–299	14	17	15.16 ± 1.75
300–349	12	13	11.84 ± 1.57
350–399	12	27	10.41 ± 0.96
400–449	11	24	13.94 ± 1.36
450–499	13	27	10.34 ± 0.95
500–549	9	30	11.50 ± 1.00
550–599	8	16	8.00 ± 0.95
600–649	7	13	15.60 ± 2.06
650–699	6	9	11.07 ± 1.76
700–749	5	5	11.88 ± 2.53
750–799	7	6	10.18 ± 1.98
800–849	4	7	8.19 ± 1.48
Total	....	199	....
Average	....	....	12.11 ± 0.43

The data in this table are less consistent than those given in table 1 (page 225) for animals in a uniform stage of lactation. A wider range of coefficients is shown in table 10, due to the value found for the first class. The large probable error attached to this and other coefficients indicates that little reliance can be placed on them. The average coefficient is practically identical with the one found for individuals in the same stage of lactation.

It would naturally be expected that cows in various stages of lactation would be more variable than animals uniform in this respect. The reduction in milk yield during the lactation period is one factor that should cause greater variation in the former group. However, if this reduction were represented by a straight line, this factor would not be operative under the conditions of selection used in this study. Woll (1912) has shown that the monthly decrease is practically constant until the eighth month, when a more rapid fall begins. In the present study, practically all the cows were less than eight months advanced in the stage of lactation at the end of the twenty-weeks period. Therefore this factor of an accelerated rate of decrease with advancing lactation would not be operative under the method of selection used.

Another factor that becomes operative with varying stages of lactation is the decrease in milk flow due to the development of a fetus. The results of Gavin's work have already been cited showing that this decrease is not constant. However, this factor may be as largely operative in table 1 as it is in the case of the results here under discussion, for the time of service bears no definite relation to the time of previous calving.

In view of the above discussion, it is not very surprising that, under the conditions of selection used, the coefficient of variability of cows in various stages of lactation is not greater than the value for animals uniform in this respect. If the twenty-weeks period included records for the last three or four months of the lactation period, the results would doubtless be quite different.

The column *Average number of weeks after calving* is placed in the table to show that the lowest producers are the ones most advanced in the stage of lactation, and to show the decrease in the number of weeks with increasing production. This is what would be expected, other conditions being equal.

Fixed limits versus percentage limits in selecting individuals on the basis of equal production.— Brief mention has been made of the possible effect of a fixed range in class limits thruout the series, in selecting individuals of similar production. In order to determine the possible effect of this factor, the limits for selecting cows of equal production were fixed on a percentage basis. The range of each group is 10 per cent of the lower limit of the group. The range of limits thus fixed increases as the lower limit increases. Beginning at 200 the class limits are thus: 200–219, 220–241, 242–265, 266–292, and so on. The variation of individuals of similar production selected on this basis is shown in table 11:

TABLE 11. INDIVIDUAL VARIATION; PERCENTAGE LIMITS USED FOR CLASSES OF INDIVIDUALS OF EQUAL PRODUCTION

Individual production, two-weeks period (pounds)	Average number of weeks after calving	Number of individuals	Coefficient of variability
220–241	16	4	30.07 ± 7.17
242–265	12	4	23.37 ± 5.57
266–292	14	9	8.22 ± 1.31
293–321	11	9	13.51 ± 2.15
322–353	14	10	9.52 ± 1.44
354–388	12	22	10.35 ± 1.05
389–426	13	13	10.58 ± 1.40
427–469	15	23	10.37 ± 1.03
470–516	10	29	12.31 ± 1.09
517–568	10	27	10.83 ± 0.99
569–626	6	15	8.95 ± 1.10
627–689	5	12	17.25 ± 2.38
690–758	6	11	13.31 ± 1.91
759–834	5	6	7.43 ± 1.45
835–918	4	4	9.23 ± 2.20
Total	....	198	....
Average	....	....	11.75 ± 0.42

The coefficients of variability in table 11 show the same general range as those in table 10. The average value is also similar. If there is any difference due to the different systems of determining the limits, the coefficients should be larger where the range is greater in proportion to the group yield. In table 10 the limits are wider below 500 pounds, while above this figure the converse is true. Splitting each table at this point, the average coefficient for the groups below 500 pounds is 12.89 ± 0.58 for table 10 and 11.91 ± 0.54 for table 11; above 500 pounds the average coefficient is 11.08 ± 0.58 for table 10 and 11.49 ± 0.65 for table 11. Thus it is seen that the coefficients are slightly larger where the limits are wider, but the probable errors indicate that the differences are not significant. It therefore appears that there is no object in using a percentage basis of limits under the conditions of selection used.

Allowable range in selecting individuals of equal production.— In the studies previously made in selecting individuals of equal production, the range allowed has been 50 pounds. A study was made to determine the effect of a wider and of a narrower range on variation, in order to ascertain whether other limits would prove more satisfactory. First, all the cows producing from 400 to 499 pounds in the trial period were selected and their coefficient of variability was determined. Thus this measure of variation was based on the assumption that a range of not over 100 pounds in two weeks represented equal production. Next, the same animals were divided into two classes, one composed of indi-

TABLE 12. RANGE TO BE ALLOWED IN SELECTING INDIVIDUALS OF EQUAL PRODUCTION

Individual production, two-weeks period (pounds)	Range allowed by limits (pounds)	Number of individuals	Coefficient of variability
400–499	100	51	12.65 ± 0.84
400–449 450–499	50	51	12.03 ± 0.81
400–424 425–449 450–474 475–499	25	51	10.98 ± 0.74
400–412.4 412.5–424.9 425–437.4 437.5–449.9 475–487.4	12.5	34	10.68 ± 0.89

viduals producing between 400 and 449 pounds, the other of individuals producing from 450 to 499 pounds. Thus the measure of variation assuming a 50-pound range as representing equal production was obtained. Similarly, the cows were further divided into four classes, with a range of 25 pounds; and finally into eight classes, to obtain an even smaller range. The results are given in table 12.

A slight decrease in the size of the coefficients as the limits are narrowed is shown in table 12. However, the decrease is not significant when the probable errors are considered. The difference between the values for the widest and the narrowest range is 1.97 ± 1.22. The odds are only 2 to 1 that this difference is significant. Thus it appears that there is no object in using narrower limits than 100 pounds in yields for a two-weeks period in selecting individuals of equal production. Accordingly the 50-pound range used for the studies in this bulletin must be sufficiently narrow to secure the object desired.

Group variation

The variation of groups of equal production during the trial period is shown in table 13. No selection of individuals was made, the only consideration being to make the production of the groups equal within the 100-pound limits.

TABLE 13. VARIATION IN GROUPS

Group production, two-weeks period (pounds)	Number of groups	Number of cows per group	Coefficient of variability
2,700–2,799	18	6	3.86 ± 0.43
3,100–3,199	16	6	5.25 ± 0.63
Total	34	……..	………………
Average	……..	……..	4.51 ± 0.37

It is shown in this table that the variation in groups of six cows in different stages of lactation, under the conditions of selection obtaining in this study, is no greater than the variation in a similar group of the same stage of lactation. The probable reasons why the variation in stage of lactation does not result in a larger coefficient under the conditions in question, have been discussed in connection with table 10.

Effect of including aborting cows.— In the statistical studies reported in this bulletin, the importance of numbers was felt to be so great that not all the records of animals that had aborted were excluded. Inasmuch as these records constituted only six per cent of the total, even assuming that they were subject to greater variation than the records of normal individuals, the effect of their inclusion would be small. However, it was believed that under the conditions of this selection no greater variation would result. A study was made on this point. Groups of six cows were made up as follows: (1) all aborting cows; (2) all normal cows; (3) half aborting cows and half normal cows. In order to get enough aborting cows to make the results more trustworthy, the number of records of such cows used in these studies was increased by all such records in the herdbooks which satisfied the conditions of selection. The results are shown in table 14:

TABLE 14. EFFECT OF INCLUSION OF ABORTING COWS ON THE VARIATION OF GROUPS

Composition of group	Number of groups	Coefficient of variability
All aborting cows	5	3.30 ± 0.70
All normal	7	5.61 ± 1.01
Half aborting cows	7	5.20 ± 0.94

It is shown in table 14 that under the conditions of this selection aborting cows were apparently less variable than normal cows. Altho the number of groups used is too small to make the results absolutely conclusive, they indicate that aborting cows are not more variable than normal cows. The variability of mixed groups, even, shows no increase above that of groups of all normal cows, when selected on the basis used.

Hills (1896) found that abortion causes a decrease of one-third in milk flow from the production of the preceding lactation period. When aborting cows are selected on the basis of their production after abortion, however, their variation is apparently less than the variation of normal cows selected in the same way.

This discussion is included to indicate the soundness of the procedure followed. It should not, however, be concluded that animals which have aborted should be included in an experimental group. At all times in experimental work the animals used should be free from disease and from all residual effects of disease. While aborting cows are apparently no more variable when selected on the basis of production after abortion, the residual effects of the disease on the health of the animal and on her production are not known. Such an animal is diseased, is abnormal, and hence should not be included. It is of the greatest importance to use none but healthy cows in experimental work.

STUDIES OF JERSEY RECORDS: COWS IN UNIFORM STAGE OF LACTATION

Enough Jersey records were available to permit of a little corroborative work with this breed. The study was made in a similar way to the study of Holsteins in which the records of production for a twenty-weeks period began one month after calving. Only cows that freshened between August 15 and December 15 were used.

Individual variation.

The records were first sorted into groups of equal individual production and the variation of individuals was thus determined. The results of this study are shown in table 15:

TABLE 15. INDIVIDUAL VARIATION

Individual production, two-weeks period (pounds)	Number of individuals	Coefficient of variability
150–199	7	7.02 ± 1.27
200–249	17	12.13 ± 1.40
250–299	23	15.33 ± 1.52
300–349	32	11.42 ± 0.96
350–399	18	9.13 ± 1.03
400–449	9	13.18 ± 2.10
450–499	6	4.70 ± 0.92
Total	112	....
Average	....	11.47 ± 0.53

The coefficient of individual variation for Jerseys, as shown by the average value listed in table 15, is nearly identical with the corresponding figure for Holsteins as shown in table 1.

Group variation

In the study of group variation the individuals were chosen at random, the only consideration being to have the group production fall within the limits prescribed. The results are shown in table 16:

TABLE 16. VARIATION IN GROUPS

Group production, two-weeks period (pounds)	Number of groups	Number of cows per group	Coefficient of variability
1,900–1,999	18	6	4.25 ± 0.48

The value found for the coefficient of variability for Jerseys in groups of six made up of unselected individuals is similar to the figure found for Holsteins. The calculated value on the basis of the average coefficient for individual variability shown in table 15 was found to be 4.68. This checks closely with the observed figures shown in table 16.

EFFECT OF AGE ON THE PRODUCTION OF DAIRY COWS

The herd records used in the foregoing investigations afforded an opportunity for some additional study on the effect of age on the production of dairy cows. In discussing the variability of mature and of immature cows, the question arises as to when a cow is mature. In order to answer this question, and also to trace the increase of production from the first lactation to the lactation of maximum production, the following study was made.

All the cows of all breeds were used for which records of production were available for at least four lactations, beginning with the first. Records of the production of seventy-nine individuals were obtained, ranging in length from four to eleven lactations. Production for each lactation was taken, rather than production per year, since a calendar year beginning in any month would include parts of two lactations for a large number of cows. Altho the lactations of individuals vary considerably in length, the average lengths of the various lactation periods of numbers of cows agree closely.

In getting the average production of cows for each of the first four lactations, the records of all cows were used. This gave the records of seventy-nine cows for four lactations. Likewise, in getting the average production of cows for each of the first five lactations, the records of all cows were used which had completed five lactations. There were sixty of these cows. In a similar way the average production per lactation for six, seven, eight, nine, and ten lactations was obtained. Only four cows had completed ten lactations.

The relation of age to milk production is shown graphically in figure 59 (page 241). The maximum milk production of these cows was not reached until the eighth lactation. Only fourteen cows had completed eight lactations, and hence the data are not conclusive. The consistency of the longer curves of fewer cows with the shorter curves of a larger number of cows — as far as the latter go — tends to substantiate the above conclusion. Cows five years of age are ordinarily considered to be mature. The average production of sixty cows for five lactations shows that their maximum production was not reached before the fifth lactation, corresponding to an age of from six to seven years.

Pearl and Patterson (1917) have shown that the maximum seven-day milk production of Jersey cows is reached between eight and nine years of age. Miner (1915) has shown that the maximum seven-day fat production of Holstein cows is also reached between eight and nine years of age. Both these studies were made with seven-day records. The larger number of individuals used gives a smoother curve and greater certainty to the results. The curve presented in this bulletin shows that maximum production for a whole lactation was reached during the eighth lactation, which corresponds to an age of from nine to ten years. The close agreement of these results of yearly records for a few cows, with seven-day records for larger numbers tends to substantiate the former. Probably maximum production is reached somewhat later in life than is ordinarily supposed.

The curves (fig. 60) showing the relation of age to fat production agree very closely with those for milk production.

In studying the relation of the production of a cow for her first lactation to the production for her lactation of maximum production, the difficulty has been in finding out which is the lactation of maximum production. The foregoing study indicated that the maximum production of these cows was reached during the eighth lactation. As already stated, only fourteen cows had completed eight lactations and therefore the results are not so trustworthy as is desirable. The averages for the fourteen cows for eight lactations are given in table 17:

TABLE 17. RELATION OF AGE TO MILK PRODUCTION
(Averages of 14 cows for 8 lactations)

Lactation	Milk production (pounds)	Number of days milked	Per cent of maximum production
1	7,511.9	345	68
2	7,266.9	289	65
3	9,179.8	331	83
4	8,961.2	321	81
5	9,529.8	308	86
6	9,621.1	318	86
7	10,399.6	327	93
8	11,123.9	352	100

For purposes of comparison the averages of sixty cows for five lactations are given in table 18. The data indicate that these cows had not yet reached their maximum.

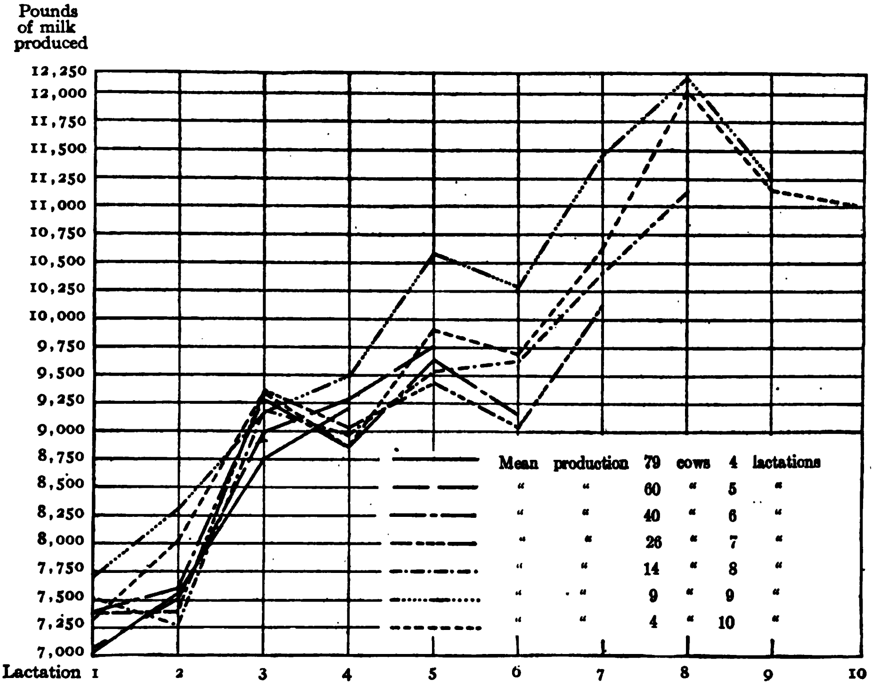

FIG. 59. RELATION OF AGE OF COW TO MILK PRODUCTION

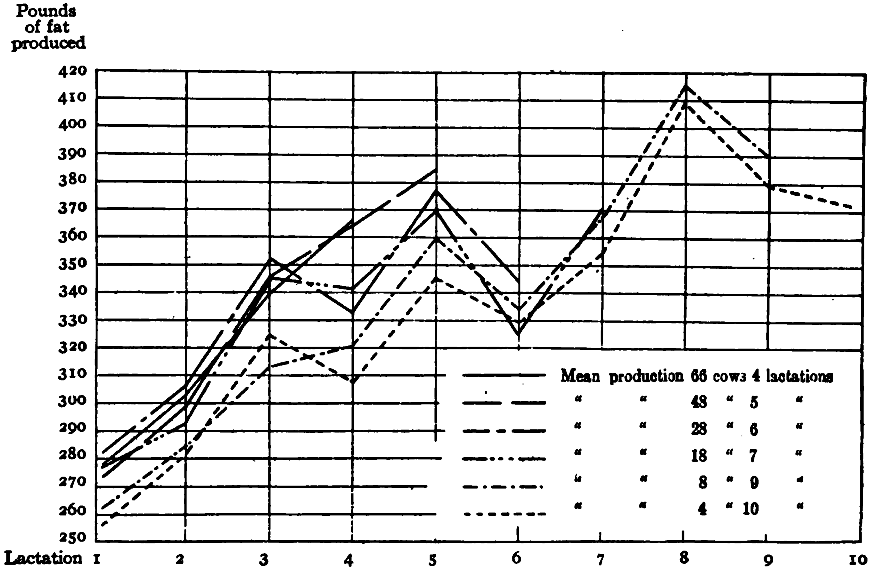

FIG. 60. RELATION OF AGE OF COW TO FAT PRODUCTION

TABLE 18. RELATION OF AGE TO MILK PRODUCTION

(Averages of 60 cows for 5 lactations)

Lactation	Milk production (pounds)	Number of days milked	Per cent of production for fifth lactation
1	7,055.1	333	72
2	7,502.4	310	77
3	8,991.1	324	92
4	9,282.4	316	95
5	9,757.8	323	100

It would be expected that the period of maximum seven-day production of a cow would fall in or near the lactation of maximum production. This, however, has not been proved. The chief interest of the practical breeder lies in the relation of age to the annual production of cows. Few herd records contain enough data to give much light on this question. While the limitations of the relatively small number of records are recognized, the data are here included for what they are worth. They represent all the records of cows that up to the present time have completed at least four lactations, recorded in the university herdbook. These records, which have been kept for the past thirty years by Professor H. H. Wing, include the records of some four hundred animals of all breeds.

The data from which the curves of milk production were made are given in tables 19 to 25, inclusive:

TABLE 19. RELATION OF AGE TO MILK PRODUCTION

(Averages of 79 cows for 4 lactations. Age at freshening, 27 months)

Lactation	Milk production (pounds)	Number of days milked	Number of days dry	Per cent of production for fourth lactation
1	7,018.4	335.0	55.7	76
2	7,553.4	309.0	66.0	82
3	8,750.6	322.4	62.2	95
4	9,200.7	319.2	57.5	100

TABLE 20. RELATION OF AGE TO MILK PRODUCTION
(Averages of 60 cows for 5 lactations)

Lactation	Milk production (pounds)	Number of days milked	Number of days dry	Per cent of production for fifth lactation
1	7,055.1	333.1	53.6	72
2	7,502.4	309.8	67.6	77
3	8,991.1	324.2	61.2	92
4	9,282.4	315.8	62.4	95
5	9,757.8	323.3	59.8	100

TABLE 21. RELATION OF AGE TO MILK PRODUCTION
(Averages of 40 cows for 6 lactations)

Lactation	Milk production (pounds)	Number of days milked	Number of days dry	Per cent of production for fifth lactation
1	7,385.2	338.2	47.4	77
2	7,592.8	311.9	68.4	79
3	9,284.9	329.1	55.4	96
4	8,846.8	307.4	56.3	92
5	9,637.8	326.4	62.3	100
6	9,152.7	314.6	62.4	95

TABLE 22. RELATION OF AGE TO MILK PRODUCTION
(Averages of 26 cows for 7 lactations)

Lactation	Milk production (pounds)	Number of days milked	Number of days dry	Per cent of production for seventh lactation
1	7,376.6	346.0	53.2	73
2	7,383.6	297.8	55.5	73
3	9,367.7	331.0	53.0	92
4	9,027.6	314.0	54.3	89
5	9,432.2	316.3	53.0	93
6	9,034.4	315.0	73.6	89
7	10,127.0	330.7	62.0	100

TABLE 23. RELATION OF AGE TO MILK PRODUCTION

(Averages of 14 cows for 8 lactations)

Lactation	Milk production (pounds)	Number of days milked	Number of days dry	Per cent of maximum production
1	7,511.9	345.1	54.6	68
2	7,266.9	289.1	55.7	65
3	9,179.8	331.2	50.4	83
4	8,961.2	321.5	54.4	81
5	9,529.8	308.4	50.4	86
6	9,621.1	318.2	66.9	86
7	10,399.6	327.7	66.9	93
8	11,123.9	352.0	59.6	100

TABLE 24. RELATION OF AGE TO MILK PRODUCTION

(Averages of 9 cows for 9 lactations)

Lactation	Milk production (pounds)	Number of days milked	Number of days dry	Per cent of maximum production
1	7,706.5	335.4	59.4	63
2	8,302.0	303.9	51.1	68
3	9,163.0	319.1	48.7	75
4	9,492.7	332.2	52.4	78
5	10,578.9	316.1	48.0	87
6	10,276.3	309.6	62.4	85
7	11,433.0	344.8	68.0	94
8	12,153.9	345.4	67.2	100
9	11,241.0	344.4	35.9	92

TABLE 25. RELATION OF AGE TO MILK PRODUCTION

(Averages of 4 cows for 10 lactations)

Lactation	Milk production (pounds)	Number of days milked	Number of days dry	Per cent of maximum production
1	7,311.0	307.5	64.2	61
2	8,025.8	301.0	46.2	67
3	9,342.4	327.5	48.7	78
4	8,848.5	312.5	58.5	74
5	9,899.2	303.0	39.2	82
6	9,688.0	322.0	73.2	81
7	10,619.4	316.0	69.8	88
8	12,015.2	334.0	64.0	100
9	11,147.0	339.0	80.8	93
10	11,002.0	293.0	26.5	92

SUMMARY

It is shown by the foregoing statistical studies that Holsteins in the same stage of lactation, selected on the basis of approximately equal production during a two-weeks period, are subject to a coefficient of individual variability of 11.87 ± 0.43 in a following period of eighteen weeks. Under the conditions of selection used in which the eighteen-weeks period was completed while the decrease in milk production due to advancing lactation remained approximately uniform, the coefficient of variability was not materially increased by using animals in various stages of lactation. In a study with Jerseys in the same stage of lactation the coefficient of variability was found to be 11.47 ± 0.53.

Studies as to the variation of groups resulted in coefficients for group production which checked closely with the values calculated from the figures for individual variation. This furnishes evidence as to the accuracy of the values for individuals, and of the methods used.

It is shown that groups of unselected individuals are more variable than groups made up of individuals of equal production. Groups of animals of the same age are shown to be less variable than groups including all ages. A study of the first four lactations did not show any differences in variability among them.

Groups selected on the basis of yields during the preceding lactation are shown to be more variable than groups selected on the basis of a preliminary period during the lactation in question.

A study of variation in fat production as regards Holsteins resulted in a coefficient similar to that found for milk production.

Yields varying within a 50-pound range during a two-weeks preliminary period are considered as equal production as regards individuals. It is shown that variation is not decreased appreciably by using a smaller range. Similarly, it is shown that there is no object in using a smaller range than 100 pounds for the two-weeks period in selecting groups of six of equal total production. It is shown further than when limits as narrow as the ones stated above for individuals are employed, there is no object in using percentage limits — that is, limits in proportion to the yield.

Probably the maximum production of cows is reached later in life than is commonly supposed. The cows used in this study did not reach their maximum production until the eighth lactation, corresponding to an age of from nine to ten years.

APPLICATION OF RESULTS OF STATISTICAL STUDY

In considering the application of the results of the studies described in the foregoing pages, attention must be given to the conditions under which the studies were made. In the first place, the continuous system of conducting feeding experiments was the method under consideration. Secondly, an experimental period of eighteen weeks was arbitrarily chosen, for reasons already mentioned. Finally, use was made of the records of the general college herd, not of animals on experiment. The reasons for using such a group of animals have been given.

It is believed that data are presented that will make possible a more intelligent use of the continuous system of feeding experiments. These data should aid the investigator in planning experiments so as to obtain results capable of interpretation. The results given here should aid in determining what variation may be expected under the conditions of selection possible in a given case. It is further believed that these studies should convince workers of the necessity of a statistical analysis of results before conclusions are drawn.

Variation of similar individuals and groups, even when selected carefully and treated uniformly, is a fact to be acknowledged and considered. Hence, in an experiment in which two or more groups of animals of similar productive capacity are used, one group will always produce more than the others. This may be due to the causes considered in the experiment, or it may be in spite of them. In such experiments, conclusions should not be drawn from inconclusive results.

Statistical analysis of the results of feeding experiments is an aid in interpreting the results. The greatest advantage of the statistical method is that it eliminates personal bias and preconceived conclusions, and gives the mathematical chances for or against a proposition. Even odds of 30 to 1 in favor of a conclusion do not give absolute certainty. The statistical method of analysis will not take the place of judgment, but it is a valuable adjunct to judgment in evaluating results and formulating conclusions.

It cannot be determined how closely the figures found for individual variation over a period of eighteen weeks would apply to periods of other durations. It is believed that for periods of approximately the same length the application would be very close, while for periods of much longer duration the value reported should at least serve as a guide. In considering the application of the results as to the influence of certain selective factors on variation, their value is not limited by the fact that a period of definite length was used. Rather, these results should have a general application.

In making up groups of animals for feeding experiments the following points should be considered:

1. Groups should be selected on the basis of production for a trial period just preceding the experimental period.

2. The cows in a group should be of approximately equal individual production.

3. The cows in a group should be as nearly as possible of the same age. There is no indication that cows of any particular age are more variable than those of any other age, but for other reasons it seems desirable to exclude heifers.

4. Cows in a group should be in approximately the same stage of lactation. There is apparently no increase in variability caused by mixing cows in different stages of lactation, so long as the experimental period is completed before the rapid decrease in production begins. According to Woll (1912), this rapid decrease begins at about the eighth month, and hence, if a period of about five months is to be used, the cows should have freshened not more than three months before the beginning of the period.

5. Only healthy, vigorous, normal, mature cows should be included.

6. Groups should be made as large as possible without sacrificing more important factors.

In planning a feeding trial the experimenter should generally have some idea as to the difference in production that may be expected with the rations used. In order to get results that may be considered reasonably certain, the percentage difference in total production should be about three times the normal variation due to individuality. Knowing the probable coefficient of individual variation under the conditions of selection used, the experimenter can determine how many animals he must include in a group in order to get significant results. If this number of animals is not available, repetition of the experiment may be necessary.

In some cases the experimenter may not have much of an idea as to what differences in production he may expect. Even in this case a consideration of the coefficient of normal variation will be useful, if only in preventing him from conducting an experiment from which significant results could not be obtained.

In any case a statistical analysis of the results should be made before any interpretation is placed on them. The relation of the percentage difference in total production obtained by the experiment, to the coefficient of variability to be expected with the groups as selected, gives the best evidence of the trustworthiness of the results.

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